





गुरुकुल कांगड़ी विश्वविद्यालय, हरिद्वार

पुस्तकालय



विषय संख्या

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आगत पंजिका संख्या

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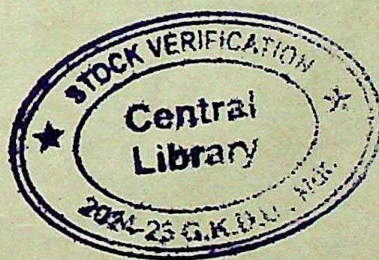
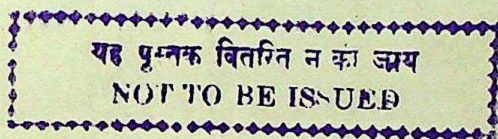
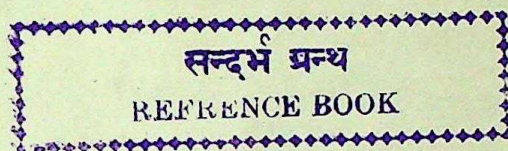
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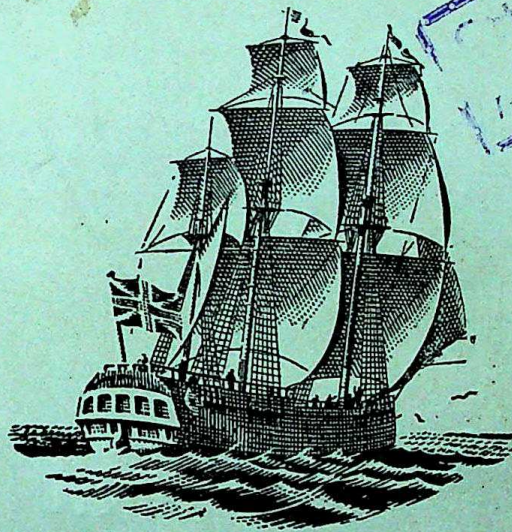
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ENDEAVOUR



Volume XVI

Number 61

JANUARY 1957

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ENDEAVOUR

The British quarterly scientific journal *ENDEAVOUR* was first published, by Imperial Chemical Industries Limited, in January 1942. Its purpose is to provide scientists, especially those overseas, with news of the progress of the sciences. While emphasis is laid upon British work, occasional articles from overseas contributors are included and impartial reference is made to the world's scientific literature. To make the journal truly international in character it is published in five separate editions—English, French, German, Italian, and Spanish.

No charge is made for *ENDEAVOUR*. It is distributed to senior scientists, scientific institutions, and libraries throughout the world, the guiding principle being that of helping scientists overseas to maintain those contacts which their British colleagues have always so much valued. Within these limits the Editors are at all times glad to consider the addition of new names to the mailing list.

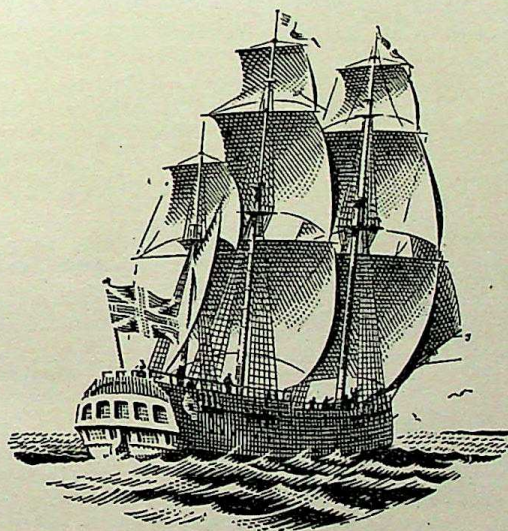
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COMPILED

ENDEAVOUR

A quarterly review designed to record the progress
of the sciences in the service of mankind



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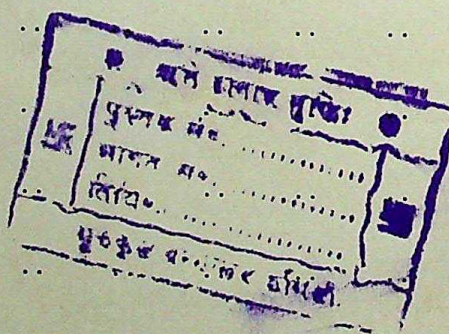
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Imperial Chemical Industries Limited, Millbank, London, S.W.1

Communications to the Editor should be addressed to North Block, Thames House, Millbank, London, S.W.1

Heinrich Hertz (1857-1894)

गुरुकुल
सामाजिक विद्यालय
हरिद्वार

In the hands of the great geometers of the eighteenth century, Newton's law of gravitational attraction was so successful in accounting for the observed motions of the planets that attempts were made to account for most of the properties of matter in terms of direct attractions or repulsions across space, varying solely with distance.

According to Newton's law of gravitation, the attraction between two bodies depends only upon their distance apart and is not affected by any intermediate matter, but Newton himself was not a believer in action at a distance, in which the intervening medium plays no part. Nevertheless, the doctrine of action at a distance was strongly favoured by the German and French scientific schools during the nineteenth century. In the hands of W. Weber and others the theory of electricity was developed on this basis to a state of high perfection. But so many different hypotheses were involved that they became very unmanageable.

The English school of physicists, on the other hand, did not favour the doctrine of direct action at a distance. Faraday firmly believed that the action between two electrically charged bodies was transmitted through and by the medium between them. To him it was inconceivable that direct action between bodies separated in space was possible without any change taking place in the intervening medium. He pictured the latter as the seat of a system of stresses, which could be represented by an attraction or tension along the lines of electric force at every point, together with a lateral pressure or mutual repulsion of these lines.

The translation of Faraday's ideas into a mathematical form was the great work of Clerk Maxwell. His theory, in its fully developed form, was published in 1873 in his classic treatise on 'Electricity and Magnetism', in which he showed that all electric and magnetic phenomena could be reduced to stresses and motions of a material medium. He demonstrated that the propagation of electric disturbances resembles that of light, and he did not hesitate to assert the identity of the two phenomena. He pointed out that if the medium required for the explanation of electromagnetic phenomena is the same as that required for the explanation of the phenomena of light, the velocity of light in vacuo should be numerically the same as the ratio of the electromagnetic and electrostatic units. The best determination at that time appeared to confirm that this was so. Hence,

Maxwell concluded, 'we can scarcely avoid the inference that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena.'

Maxwell's theory involved novel conceptions, in particular the conception of a displacement current in a dielectric medium, proportional to the rate of increase of the electric force in the dielectric, which produces the same magnetic effects as a true current. By including the displacement current as a continuation through the dielectric of the current employed in charging a condenser, the current became a circuital vector; it could be regarded as flowing in a closed circuit. To most of Maxwell's contemporaries these conceptions were so far removed from contemporary views based on action at a distance that they found great difficulty in accepting them. It was largely due to the work of Heinrich Hertz, the centenary of whose birth occurs this year, that Maxwell's theory was established and became generally accepted. Hertz discovered the electric waves whose existence had been deduced by Maxwell as an essential consequence of his theory, and showed that their properties were similar to those of light waves. He thereby provided the experimental proof of the hypotheses on which the theory was based.

Hertz was born on 22nd February 1857 in Hamburg. While attending the high school of his native town, he spent much of his leisure time constructing optical and mechanical instruments. At the end of his school career he decided to become an engineer; as his studies progressed, however, he became increasingly attracted to pure science, and after two years he decided to abandon the engineering training in favour of an academic career. In the autumn of 1878 he went to Berlin and worked in the laboratory of Helmholtz, who quickly realized that in Hertz he had a pupil of quite outstanding talent and who, in October 1880, appointed him his assistant.

In 1883 Hertz became a *Privatdozent* at Kiel, where he began a serious study of 'Maxwellian electromagnetics' and in 1884 published a paper in which he attempted to justify Maxwell's equations on theoretical grounds, reaching the conclusion that for various reasons Maxwell's system was to be preferred to the opposing system based on direct action at a distance. On his appointment in 1885 as Professor of Physics at Karlsruhe, Hertz turned his attention to the possibility of

verifying Maxwell's theory by direct experiment.

In his first experiment, a piece of copper wire was bent into the form of a rectangle, leaving a short air gap between the ends of the wire. When this was connected by a wire to a circuit through which the spark discharge of an induction coil was passing, he found that a spark passed in the air gap of the open circuit. He next found that the spark could be induced in the open circuit in the absence of any connection with the oscillating circuit, provided that the dimensions of the secondary circuit were such that it was nearly in resonance with the primary circuit. The open circuit thus gave him a method of detecting electrical effects at a distance from an oscillating circuit, all that was needed for observing the propagation of electric waves in free space.

Hertz constructed an oscillator consisting of two sheets of metal in the same plane, each carrying a wire projecting towards the other sheet and terminating in a knob, which was excited by connecting it to the terminals of an induction coil. The small capacitance and self-inductance of this oscillator provided him with waves of sufficiently short wavelength, about 24 cm, to be manageable in his laboratory. His detector was of dimensions such that its free period of oscillation was equal to that of the primary oscillator.

He first showed that the observed phenomena were modified if an insulating substance were brought into the vicinity of the apparatus, thus proving that electrical disturbances in insulators are accompanied not merely by electrostatic actions but also by electromagnetic actions. By transmitting the disturbance from the primary oscillator

along two different paths, through the air and along a wire, he obtained interference effects, proving that the electromagnetic actions are propagated with a finite velocity. From further experiments he concluded that the velocity of propagation was of the same order as the velocity of light.

Further experiments established the essential similarity of electric waves and light waves. By reflecting the electric waves from the surface of a wall, standing waves were produced by interference between the direct and reflected beams. By reflecting them from a metal sheet he showed that the angles of incidence and reflection were approximately equal. By transmitting the waves through an opening in a screen, he proved that they were propagated in a straight line with diffraction effects. Refraction of the waves was obtained by passing them through a prism of hard pitch, and polarization was obtained by passing them through a grating of parallel metallic wires.

These experiments were supplemented by theoretical investigations. He analysed, on the basis of Maxwell's theory, the disturbances emitted by his oscillator; he also presented the general content of Maxwell's theory for bodies at rest and extended Maxwell's equations to material bodies in motion in the field.

In 1889 Hertz received a call to the University of Bonn as Professor of Physics and during the few remaining years of his life was occupied with logical discussion of the fundamental principles of mechanics, from the most general standpoint. In 1893 he became ill and after much suffering died on 1st January 1894. His death, at a comparatively early age was a great loss to science.

In memoriam: John A. Wilcken (1881-1956)

It is with profound regret that we record the death—on 9th October 1956, in his seventy-sixth year—of Dr John Adolf Wilcken, who had been Foreign Editor of ENDEAVOUR since the journal's inception in 1942. To the devoted and meticulous care that he gave to the preparation of the four foreign language editions of ENDEAVOUR is due in large measure the success it has achieved abroad.

Born in Denmark in 1881, he had an exceptional experience of travel and of scientific work, both research and editorial, in many parts of the world. Before settling in England he had travelled extensively in Europe and had held appointments in the United States, Brazil, and Argentina; he was

a physics graduate of the Universities of Copenhagen, La Plata, and London. He first came to England in 1919, and was for a short time engaged in research at the Cavendish Laboratory, Cambridge. In 1920 he was appointed lecturer in mathematics at Sunderland Technical College, and four years later went to Armstrong (now King's) College, Newcastle-upon-Tyne, as lecturer in electrical engineering. In 1937 he went to the Institution of Electrical Engineers as editor of Section B of *Science Abstracts*; in 1940 he was appointed sole editor. This appointment he held until 1945, from which date he gave the whole of his attention to the preparation of the foreign editions of ENDEAVOUR.

Adhesion and friction

F. P. BOWDEN

Although the fundamental laws of friction are simple and have long been known, it is only comparatively recently that it has been possible to gain some understanding of the local changes that occur when one solid slides on another under various conditions. Knowledge so gained is not only important for an understanding of the physics of solids, but of great practical significance in such diverse fields as the construction and lubrication of bearings, the polishing of diamonds, the de-icing of aircraft, and the formulation of adhesives.

The experimental laws which govern the friction of solids sliding on one another are very simple. It is usually found that the frictional resistance is directly proportional to the load and is independent of the size of the surfaces in contact. A detailed examination of the contour of solid surfaces offers a ready explanation of these laws, for experience has shown that it is almost impossible, even with the best modern methods, to make a surface which is truly flat. To a person of atomic size an optically or electrolytically polished surface would look like country consisting of valleys and rolling hills differing in height by a hundred atoms or more. Most of the engineer's best surfaces have irregularities which are much greater than this and may be thousands of atoms high: they may be compared with Alpine peaks rather than hills. Putting two solids together is thus rather like turning Switzerland upside down and standing it on Austria, and the area in intimate contact will be relatively small.

Measurements of the electrical conductivity across metal surfaces placed together confirm that the real area of contact is indeed very small. It varies with the load, but for flat steel surfaces it may be less than one ten-thousandth of the apparent area. Such experiments are also interesting in that they show that the real area of contact is almost independent of the size of the surface. It is very little influenced by the shape and degree of roughness of the surfaces. It depends mainly on the load which is applied to them, and is in fact directly proportional to the load. The general behaviour is consistent with the view that the surfaces are held apart by small irregularities. This means that, even with lightly loaded surfaces, the local pressure at these small points of contact is very high and may be sufficiently great to cause the hardest metals to flow plastically. Although the stresses will cause elastic deformation of the metal in the vicinity of the points of contact, the

experiments suggest that the summits of irregularities on which the bodies are supported flow plastically and are crushed down until their cross-section is sufficient to enable them to support the applied load. The real area of contact A is given by $A = W/p_m$, where W is the load and p_m is the yield pressure of the metal. This is illustrated in figure 1.

There is strong evidence that the friction of metals is due, in large measure, to adhesion at these contact regions and represents the force necessary to shear these small junctions [1]. As a rough approximation one may therefore write $F = As$, where s is the shear strength of the junctions and F is the friction.

We see that this picture offers a simple explanation of the two laws of friction. First, since A , the real area of intimate contact, is independent of the size of the surfaces, the friction will be independent of this. Secondly, since the real area of contact A is proportional to the load, the friction will be also. If the friction is proportional to the load it means, of course, that the coefficient of friction $\mu = F/W$ is a constant.

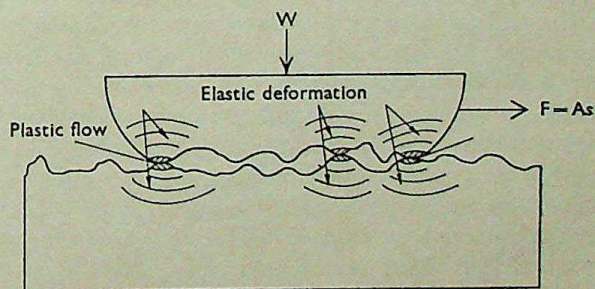


FIGURE 1—Two solids placed in contact are supported on the summits of surface irregularities. The pressure exceeds the yield pressure p_m of the solid, which flows plastically until the area of contact A is sufficient to support the load W . Hence $A = W/p_m$. The material around the regions of contact will be elastically deformed. If s is the shear strength of the junctions, $F = As$.

On occasion the shearing may occur at the interface, but more frequently (because of work-hardening of the contact region) it occurs a little distance beyond it. A metal fragment is thus detached from one of the surfaces and adheres to the other. The transfer can occur from a hard metal to a soft one as well as conversely. A convenient method of measuring quantitatively the amount of metal which is transferred at these localized regions of contact during sliding is to make one of the metals artificially radioactive and to measure the amount picked up with a Geiger counter or by an auto-radiographic technique (figure 11).

Metal surfaces exposed to the air are always covered by a film of oxide or adsorbed gas: this may be only a few molecules thick, but it has nevertheless a profound effect on the adhesion and friction. If we remove this film by heating the metals and allowing them to cool in a high vacuum, the friction is increased. If sliding is attempted the area of real contact increases, and the friction may reach an enormous value.

THE ADHESION OF METALS

We see that when two metals are placed together there is strong adhesion at the local regions of contact. It is therefore pertinent to ask why a strong normal adhesion between the surfaces is not observed. If strong adhesions are formed we might expect that the force required to pull the surfaces apart in a normal direction would be comparable with the force with which the surfaces were originally pressed together, but this is not generally observed. The reasons for this are twofold. First, in sliding there is more chance of breaking up surface-contaminating films, so that the junctions formed during sliding may be stronger than those formed under normal loading. Secondly, the friction is always measured while the normal load is retained. To study adhesion, however, the normal load must be removed before any adhesion measurements can be made. In the course of removing the normal load, the elastic stresses in the material surrounding the junctions will be released, and there will be a slight change in the shape of the interfacial contour (see figure 1). The junctions themselves, being highly worked, will be relatively brittle, and very small tensile displacements will break them. This means that as the normal load is removed, the junctions are pulled apart one by one so that practically none are left when the adhesion measurements are to be made.

If this mechanism is correct, we should expect to find strong adhesion between metals which are soft and ductile and which do not appreciably work-harden under the conditions of the experiment. With these materials, changes in shape due to elastic recovery would be small and the junctions would be sufficiently ductile to take up any movement which occurs when the normal load is removed. J. S. McFarlane and D. Tabor [2] have shown that this is indeed so. If a soft metal such as lead—or, better, indium—is prepared with a clean surface, and a hard clean spherical indenter of some other metal is pressed into the surface, marked adhesion occurs and a strong normal force is needed to pull the surfaces apart. This normal force is as large as the original load (i.e. the coefficient of adhesion is 1), and fragments of the lead or indium are found adhering to the sphere.

G. W. Rowe [3] has recently studied the adhesion in high vacuum of harder metals, such as platinum, nickel, and silver. The experiments show that although the friction of these naked metals is extremely high, the normal adhesion at room temperature is negligibly small. If, however, the temperature of the metals placed in contact is raised to a point at which annealing can occur and is then allowed to fall to room temperature, the adhesion is very strong. Some typical results for platinum surfaces are shown in figure 2. This heat treatment releases the elastic stresses at the metal bridges, and the adhesion becomes apparent. The temperature at which this occurs for a number of metals is given in Table I.

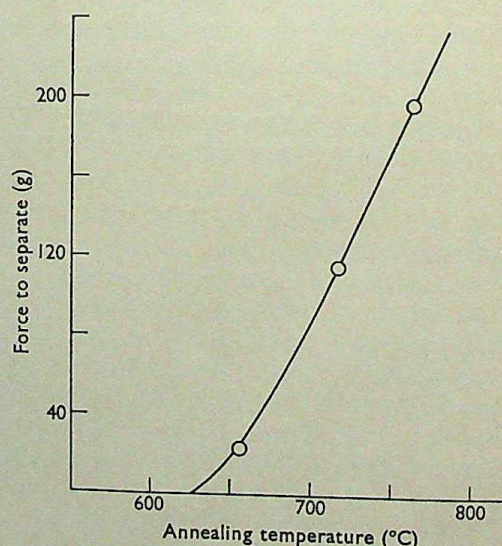


FIGURE 2 — The onset of adhesion with denuded platinum. Initial load 21 g. Adhesion is observed when annealing releases the elastic stresses.

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TABLE I

Temperature (°C) of onset of normal adhesion for metals in high vacuum

Platinum ..	620	Silver ..	200
Nickel ..	500	Lead ..	ca 30
Gold ..	250	Indium ..	< 30

If an attempt is made to slide the clean metals, the combined tangential and normal stresses will cause plastic flow of the contact regions, so that the area of contact, and hence the adhesion, will increase. Adhesion coefficients of well over 10 have been measured at room temperature. This adhesion of clean metals forms the basis of the technological process of cold welding. It is probably of importance also in the initial stages of sintering.

THE FRICTION OF PLASTICS

A study has been made of the frictional behaviour of polymeric materials. The friction of some thermoplastics sliding on themselves is given in Table II.

It is seen that all these materials have coefficients of friction of the same order as those of metals, except P.T.F.E., for which μ is phenomenally low. If a study is made of the surface damage produced during sliding it is found that there is marked adhesion, plucking, and transfer of the plastic from one surface to the other (figures 12(a) and 12(b)). When plastics slide on metals there is not only transfer of plastic to the metal but also a minute but finite transfer of metal to the plastic (figure 12(c)). It is thus possible for a relatively soft plastic to produce slight wear of a much harder metal.

It may again be shown that the friction is dependent on the real area of contact A and the

shear strength s of the junctions and may be written $F = As$. Comparison with shear strength experiments on the plastics shows that s is roughly equal to the bulk shear strength of the plastic itself, and the mechanism of friction is essentially the same as for metals.

One major difference between the frictional behaviour of these materials and of metals is the effect of load. With metals the deformation at the regions of contact is truly plastic, and for this reason the real area of contact is directly proportional to the load. With long-chain polymers this is not so. These materials are visco-elastic, and their deformation depends on the geometry of the surfaces, the load W , and the time of loading. In general, the area of contact A follows a relation of the type $A \propto W^n$ where n is less than 1. Consequently the coefficient of friction increases as the load is reduced. This effect can be very marked at light loads, and is particularly evident with polymeric fibres.

Recently M. W. Pascoe and D. Tabor [4] have measured, over a great range of load, the friction and the deformation of polymers and of fibres made from them. A schematic diagram of their apparatus for measuring the friction of fibres *in vacuo* is shown in figure 3. The lower fibre is drawn taut, and supported at both ends on a carriage which can slide along the direction of the fibre axis. It is set up *in vacuo* and driven at low speeds by a synchronous motor. The upper fibre, which acts as a cantilever, can be pressed on to the lower surface by a micrometer screw. With fine fibres normal loads as small as 10^{-6} g can be applied.

The influence of load is very marked; for example, on nylon filament (diameter 0.042 mm) the coefficient of friction μ at a load of 10^3 g is about 0.4; at a load of 10^{-3} g it is greater than

TABLE II

Polymer	Common name	Chemical formula	Coefficient of friction μ
Polyvinyl chloride	P.V.C.	$(-\text{CH}_2-\text{CHCl}-)_n$	0.4-0.5
Polystyrene ..	Polystyrene	$(\text{C}_6\text{H}_5)_n$	0.4-0.5
Polymethyl methacrylate	Perspex	$\left(\text{CH}_3-\text{C}-\text{COOCH}_3\right)_n$ $\parallel$ CH_3	0.4-0.5
Nylon		$(\text{CO}-(\text{CH}_2)_4-\text{CO}-\text{NH}-(\text{CH}_2)_6-\text{NH}-)_n$	0.3
Polyethylene ..	Polythene	$(-\text{CH}_2-\text{CH}_2-)_n$	0.6-0.8
Polytetrafluoroethylene	P.T.F.E. (Fluon, Teflon)	$(-\text{CF}_2-\text{CF}_2-)_n$	0.05-0.1

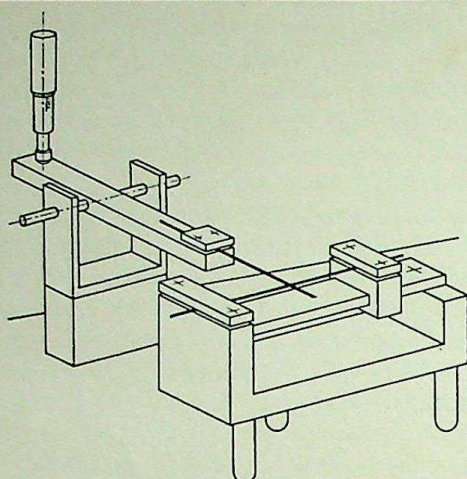


FIGURE 3—Cantilever apparatus for determining friction between fibres in vacuo.

1.2. Tabor's calculations show that this follows the variation in the true area of contact, and is essentially a reflection of the force required to shear the plastic over this area. The fibres are in general covered with minute irregularities, or 'cobblestones', so that the area of true contact may be expected to be appreciably less than the area of deformation. However, at light loads it would appear that contact occurs over only a few asperities—possibly only one. For example, with the 0.042 mm nylon fibre the largest loads used—about 0.1 g—give a circle of contact having a diameter about 0.004 mm, whereas the diameter of individual 'cobblestones' is of the order 0.002 mm. It is not possible to show the contact region at these relatively small loads, but the reflection electron micrograph of a similar fibre at much heavier loads (figure 16) illustrates this point. In this micrograph a flat metal slider was slid over the fibre at a load of 40 g. The width of the track is nearly 0.02 mm, that is, about five times the width of the widest track formed in the crossed-fibre experiments. This supports the view that in the friction measurements on crossed fibres, where the loads are very light, the contact can be considered as being single-point contact. For this reason the area of real contact is very nearly equal to the area of deformation, and the friction follows the same law as the area of deformation itself. On the basis of this simple physical picture, reasonably good frictional correlation is obtained for a load range of 10^{10} to 1 and for surfaces differing in their radius of curvature by a factor of more than 300 to 1. With most plastics the adhesion is strong; shearing takes place at a little distance from the interface, so that transfer and wear occur.

With P.T.F.E. the adhesion is small; slip may occur at the interface, and the friction is low. This appears to be an inherent property of the material, since it retains its low friction even in high vacuum, when most of the surface films would be removed. If the surface is subjected to prolonged running at high speeds the frictional heating may damage it and cause a rise in the friction. Its frictional behaviour on snow and ice will be discussed later.

ELASTIC SOLIDS. DIAMOND

The frictional behaviour of diamond is of particular interest because of its great hardness and high elastic constants. It is found that the deformation of diamond is elastic under normal loads and that the conditions at the contact region during the sliding of diamond on diamond are those of elastic deformation. This means that the area of real contact is not proportional to the load W but to $W^{2/3}$. The friction should therefore not be constant: it should decrease as the load increases, and the coefficient of friction μ should be proportional to $W^{-1/3}$. Figure 4, curve I, shows the experimental value for clean diamond exposed to air: the theoretical relationship is obeyed. It

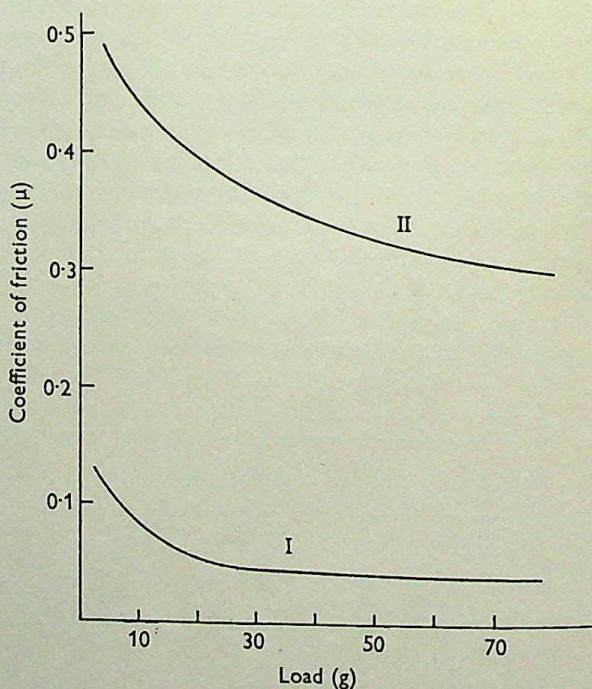


FIGURE 4—Friction of diamond as a function of load. Curve I: The coefficient of friction μ increases as the load is reduced and follows approximately a law of the type $\mu = kW^{-1/3}$ associated with elastic deformation. Curve II: In vacuo, when surface films are removed, the friction rises to a high value.

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will also be seen that the friction is small; for a load of 70 g, μ is about 0.05.

Figure 4 also shows another effect. If the adsorbed film of oxygen and other gases which is normally present on the surface is removed by heating the diamond and allowing it to cool *in vacuo*, the friction rises markedly (curve II). This effect of removing gas films is similar to that observed with metals. With metals, however, gross seizure occurs. This does not happen with diamond, simply because diamond is not ductile and junction growth cannot occur. A calculation of the real area of contact, assuming elastic deformation and using Hertz's equation, shows that for a clean diamond sliding on another *in vacuo* the effective shear strength over the region of contact is high and is comparable with the bulk strength of diamond.

There is another interesting feature about the friction of diamond on diamond. The coefficient of friction varies with the crystallographic orientation of the direction of sliding. This effect has been studied by D. M. Kenyon and more recently by M. Seal [11], and some of Seal's results are shown in figure 5. Here the coefficient of friction between a diamond slider and a polished cube (100) diamond face is plotted against the sliding direction on the face. There is evidence of fourfold symmetry in the frictional variations. The maxima occur in the directions of the crystallographic axes. These directional frictional variations add to our understanding of the mechanism of abrasion of diamond. Diamond is normally polished against a rotating iron lap or 'scaife' charged with diamond dust. It has been known for a very long time that there is a marked anisotropy in the abrasion resistance when diamond is polished in this way:

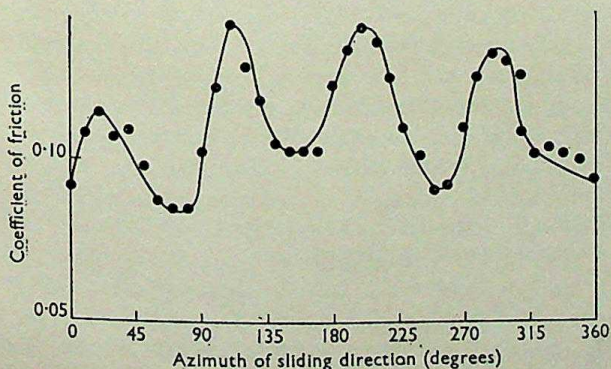


FIGURE 5—Friction of diamond is very dependent on the crystallographic direction of sliding. On a cube face it shows a fourfold symmetry. Polishing is easiest in directions of high friction.

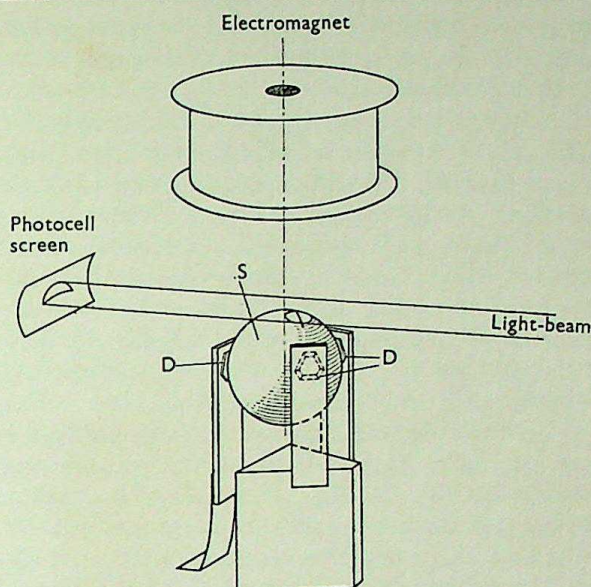


FIGURE 6—Method of studying the friction and polishing of diamond at very high speeds. The steel sphere *S* is suspended magnetically and set in rotation. The friction is measured by its deceleration when the three diamond surfaces *D* are allowed to rub against it. Rubbing speeds up to 2000 miles/hour can readily be achieved.

the difficult and easy directions differ by a factor of 1000 or more. A correlation has now been established between this abrasive wear and the coefficient of friction. Directions which resist abrasion have a low friction, and those which are more readily abraded or polished have a high friction.

While this observation does not in itself enable one to decide between the various possible abrasion mechanisms, it is consistent with a mechanism for which we have other evidence. This suggests that the attrition of the diamond may be due in part to burning or graphitization at local 'hot-spots'. On a simple theory, the temperature of the 'hot-spots' is directly proportional to the coefficient of friction. The directions of high friction, therefore, have very hot 'hot-spots' and the rate of abrasion is high. It is very difficult indeed to abrade the octahedron (III) face on diamond, and this face shows a low friction in all directions (μ approximately 0.05).

THE FRICTION AND POLISHING OF DIAMOND AT VERY HIGH SPEEDS

The rubbing speed of the 'scaife' used for polishing diamonds varies, but it is seldom higher than about 30 metres/second. Since intense local heating of the surface is an important factor we

might expect that it would be easier to polish diamonds if very high rubbing speeds were used.

E. H. Freitag is studying the friction and wear of metals at very high speeds of sliding, and the experiments have recently been extended to diamond surfaces. The experimental method, which is based on the elegant technique developed by J. W. Beams [5] for his ultracentrifuge, is illustrated in figure 6. A steel sphere is suspended by an electromagnet; it is illuminated, and the shadow falls on a photoelectric cell. If the ball sinks, the current in the magnet will increase. If it rises, it will decrease, so that the ball 'floats'. The ball, which is surrounded by an evacuated glass envelope, can be caused to rotate by a rotating magnetic field. When it has reached an appropriate speed it is allowed to rub against three flat diamond surfaces. The deceleration of the ball, and hence the friction, is measured by a photo-multiplier which observes a mark on the top of the ball. With this apparatus it is possible to achieve rubbing speeds greater than 1000 metres/second (2000 miles/hour). Typical results for a steel surface rubbing on diamond are shown in figure 7, curve I. As the speed is increased the coefficient of friction decreases: $\mu = 0.02$ at a speed of about 200 metres/second. If the speed further increases, however, there is a sudden increase in the friction, and at a sliding speed of *ca* 250 metres/second the friction rises to $\mu = 0.2$. An examination of the diamond surfaces offers an explanation of this. Figure 13 (*left*) shows the diamond surface when the rubbing speed exceeds 250 metres/second: this is a natural diamond surface, and characteristic trigons can be seen. The diamond

surface is undamaged, and metal is merely smeared over its surface. The behaviour is consistent with earlier observations that at these very high speeds the high temperature causes softening and melting of the metal to take place on a considerable scale.

The change in the diamond surface which is produced by rubbing at speeds just below 250 metres/second is shown in figure 13 (*right*). This is the hard octahedral face of a diamond which is difficult to polish by conventional methods, but nevertheless the steel sphere which has been in contact with it for only a few seconds has polished a crater in its surface. This observation is of some interest, since it shows that if the rubbing speed is sufficiently high, about 250 metres/second, it is possible to polish a diamond without the aid of diamond dust merely by rubbing a metal against it. It is consistent with the view that the polishing and abrasion are due, in an important measure, to the high-temperature burning or graphitization of the diamond. If the rubbing speed is too high, a comparatively large-scale softening of the metal surface occurs, the friction is high, metal is smeared on the surface, and no polishing takes place. If the steel sphere is coated with copper a similar effect, and a similar transition in the friction, are observed (curve II, figure 7), and occur, as we should expect, at a lower speed because the melting point of copper is lower than that of steel. The rubbing speeds which produce polish on the diamond are higher, by an order of magnitude, than the speeds used in the ordinary methods of polishing with a disk impregnated with diamond duct. The surface finish produced on the diamond by rubbing it with steel at an appropriate high speed is a good one. These observations may be of practical interest, since they show that if the speed is sufficiently high very hard solids may readily be abraded or polished by soft ones. It will be shown in the next section that this process may be aided if the surfaces, at the high temperatures developed, react chemically with one another or form solid solutions.

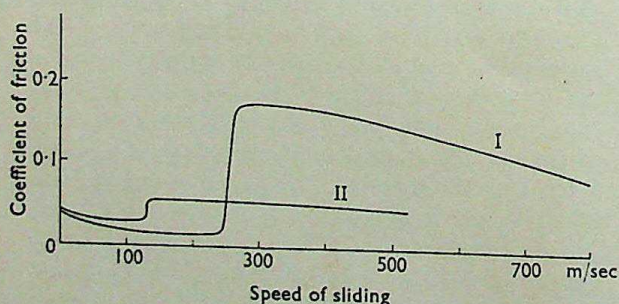


FIGURE 7—Curve I: The high-speed friction of steel on diamond. At first the friction decreases with speed, but when this reaches 250 m/second there is a sudden rise in the friction. This is associated with high-temperature softening and melting of the ball and the smearing of metal over the diamond surface (see figure 13 (*left*)). At speeds just below this the diamond is readily polished (see figure 13 (*right*)). At still lower speeds no polish occurs. Curve II: Analogous results for copper; the transition occurs at a lower speed because of the lower melting point of copper.

INFLUENCE OF TEMPERATURE ON THE FRICTION OF GRAPHITE

It has long been known that the friction of carbon when in the form of graphite is low ($\mu \approx 0.15$). This has been attributed to its lamellar structure, which allows it to shear readily. Work both in America [6] and in Britain [7] has shown that this is an over-simplification. If the graphite is thoroughly outgassed by heating in a

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vacuum the friction rises considerably ($\mu = 0.5$) and there is an enormous increase in the rate of wear. Small amounts of oxygen or water vapour can reduce the friction of outgassed graphite to its normal atmospheric value. It would seem, therefore, that the low friction of graphite is due at least in part to the action of these contaminants. Recently Kenyon has measured the friction of graphite sliding on itself and on metals at high temperature and in a high vacuum. With graphite sliding on itself the friction at room temperature is high ($\mu = 0.6$), but as the temperature is raised it falls, and at 2000°C it has fallen to $\mu = 0.2$. This may be due to a weakening, at the high temperature, of the binding forces between the lamellae. With graphite sliding on copper, silver, or gold similar results are obtained, and the friction falls steadily until the melting point of the metal is reached. With other metals, however, such as iron, nickel, thorium, titanium, molybdenum, tantalum, and tungsten, the behaviour is very different. The initial fall is observed, but at temperatures in the region of 1000°C the friction begins to increase and may reach very high values ($\mu > 2$). Metals which give this large increase in friction are those which are capable of forming carbides or solid solutions with the graphite. When this interaction occurs the area of contact A is increased and the layer at the surface, which may be a metallic carbide, will have a high shear strength, so that the friction may become very great. Copper, silver, and gold do not interact in this way, and they continue to give a low friction even when heated to within a few degrees of their melting point.

THE FRICTION OF WOOD

An interesting attempt to study the frictional behaviour of a more complex solid such as wood is being made by D. Attack. Preliminary results suggest that the frictional resistance to slow-speed sliding of metals on wood is a simple combination of a deformation and an adhesion term. That such a simple mechanism should obtain is at first sight surprising, since wood is a complex biological material, having a highly porous gel structure and exhibiting extensive physical and chemical heterogeneity.

A detailed study of the rolling and sliding of steel and P.T.F.E. spheres on two similar wood species of relatively simple anatomy, Eastern Spruce (*Picea glauca*) and Balsam (*Abies balsamea*), as a function of moisture content has been made. Clean wood specimens were selected and abraded

with fine emery under water. Sliding and rolling were conducted across the grain in the spring wood portion of spruce sapwood and balsam heartwood.

Typical results for wood with moisture contents exceeding 30 per cent. are shown in figure 8. It is seen that the sliding friction μ_s is dependent upon ball diameter and load. Tabor [8] has shown recently that the rolling friction of a ball on rubber or on metal is due primarily to an elastic hysteresis loss within the solid. The rolling resistance on wood, which is shown indirectly in figure 8, has been analysed in a similar manner, and the results show that it too is due almost entirely to elastic hysteresis loss in the wood. Lubricants have little or no effect upon the rolling friction values, indicating that interfacial slip or adhesion does not contribute to the resistance to rolling. It seems reasonable to assume, therefore, that

$$\mu_{\text{sliding}} = \mu_{\text{rolling}} + \mu_{\text{adhesion}}$$

The value of μ_{adhesion} calculated in this manner is independent of both ball diameter and load, and may be interpreted in a manner similar to that used for the sliding of metals. A surprising feature is that the curves in figure 8 represent the behaviour for both spruce sapwood and balsam heartwood under equilibrium sliding and rolling conditions. Evidence from similar studies on paper indicates that for both wood and paper the

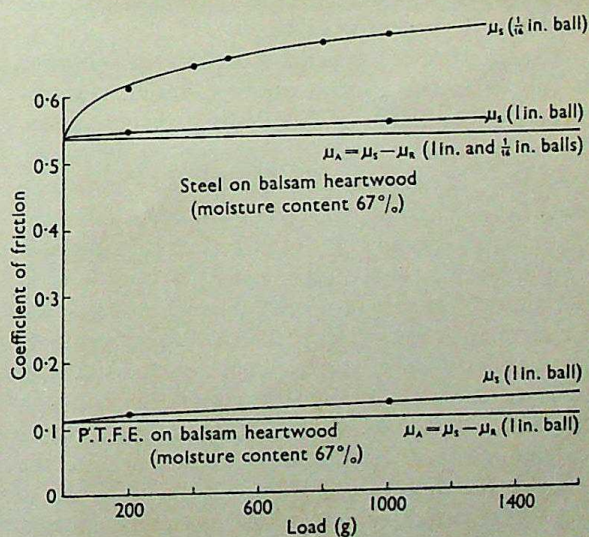


FIGURE 8—Sliding friction of wood, μ_s , can be resolved into two components, friction due to elastic hysteresis loss in deforming the wood, μ_R (this is the same as rolling friction), and friction due to adhesion between the surfaces, μ_A . μ_A follows the same laws as the friction of metals and is probably due to hydrogen bonding between the surfaces.

adhesion is due to hydrogen bonding between unbonded hydroxyl groups in the cellulose and the oxide layer on the steel surface. This would explain the low value of the adhesion term in the case of P.T.F.E. sliders, when such bonding is inhibited. The rolling friction of a P.T.F.E. sphere on wood is almost equal to that of a steel sphere of equal size under otherwise identical conditions. An increasing amount of plastic deformation for rolling and sliding occurs as the moisture content of the wood drops below 30 per cent. This deformation may be calculated approximately in terms of the bulk properties of the wood. Some understanding of the frictional behaviour of wood is important to the paper industry, since wood is disintegrated into its component fibres by frictional methods. It is interesting that so complex a solid may on occasion behave physically in a simple fashion.

ADHESION AND FRICTION OF ICE AND SNOW

The adhesion of ice to aircraft and also to ships sailing in icy seas is still a major problem, and L. E. Raraty has been studying some of the factors which influence this adhesion. His experiments show that if metal surfaces are really free from contaminating grease films the adhesion of ice to all metals is greater than the strength of ice, so that any break must occur in the ice itself. For these reasons, the behaviour is determined by the mechanical properties of ice.

The fracture of ice bears a certain resemblance to that of metals in that under different circumstances either brittle or ductile fracture can occur. Under the conditions of Raraty's experiments, there is evidence that in the temperature range zero to -6°C the failure is ductile. It is influenced by the rate of plastic deformation, and is very dependent on temperature. Below -6°C the failure occurs by brittle fracture and the strength is no longer dependent on temperature. A small amount of contaminant, such as a fatty acid, on the surface will reduce the adhesion to a low value and the failure will occur in the layer of contaminant. If the layer is incomplete, the adhesion is determined primarily by the area of the metal which remains free from contaminant. A small amount of detergent dissolved in the water will appreciably reduce the apparent adhesive strength, but there is evidence that this is due mainly to a reduction in the strength properties of ice.

Raraty has also examined the adhesion of ice to

non-metallic solids, particularly to plastics. The general behaviour is analogous to that obtained with metal surfaces, and with some plastics the surface adhesion is again stronger than the cohesion of ice itself. This is not true of all materials, however, and in particular the adhesion to the surface of P.T.F.E. is very small indeed and the break apparently occurs at the interface itself.

Although ice can adhere strongly to appropriate surfaces, the sliding friction on snow and ice is very low ($\mu \approx 0.03$). Osborne Reynolds [9] has suggested that this is due to a water film formed by pressure melting. Our experiments have shown [10], however, that this could be significant only at temperatures very close to zero and with slow-moving surfaces. If the sliding speed is appreciable and the temperatures are below zero, the local surface melting is produced not by pressure melting but by the frictional heating of the sliding surfaces. Table III illustrates the very large drop in friction which occurs when the sliding speed reaches a few metres per second. The results were obtained with variously treated skis. There is evidence that in skiing it is this frictional heating and melting which is the major factor responsible for the low friction.

TABLE III

Influence of speed on friction on ice at -10°C

Ski surface	Coefficient of friction (μ)		
	Static	At 3 cm/s	At 5 m/s
Waxed wood ..	0.20	0.18	ca 0.02
Lacquered wood ..	0.40	0.36	ca 0.03
Perspex ..	0.35	0.32	ca 0.03
Aluminium ..	0.38	0.34	ca 0.04

For the past several years I have been combining science with pleasure by investigating in the Alps the mechanism of skiing. A study has been made of the behaviour of a variety of solids, including some new plastic materials, when sliding on ice and snow [10]. Very cold snow behaves like any other crystalline solid, and the results support the early conclusion that the low friction is due to a localized surface melting produced by the frictional heating of the sliding ski. There is evidence that the frictional behaviour is influenced by the contact angle which the water film makes with the surface. P.T.F.E. has interesting possibilities, partly because of its inherently low friction

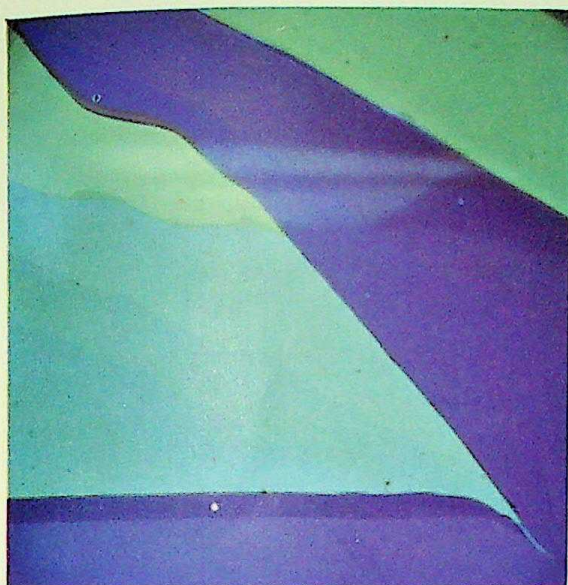


FIGURE 9 - Multiple-beam interference of cleaved sheet of mica. The regions of uniform colour are molecularly smooth, and the boundaries represent an abrupt change in thickness. ($\times 15$)

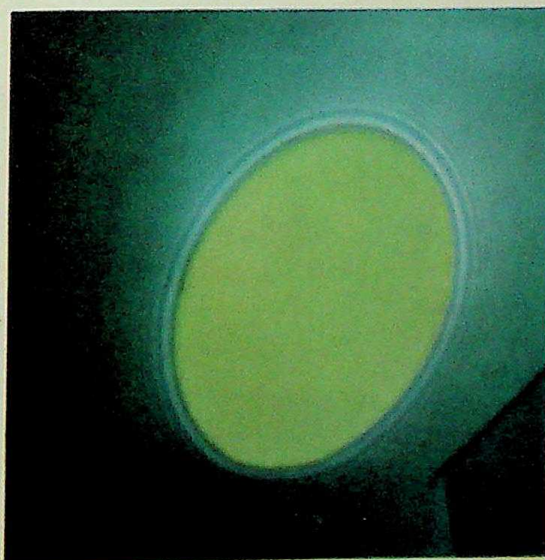


(a)

FIGURE 10 - (a) Region of contact between molecularly smooth mica surfaces. Contact is imperfect because of small particles of contamination. A separation of only a few Angströms can be detected. (b) The same. The surfaces are in molecular contact over the whole region of uniform colour. The colour fringes at the edge are formed where the sheets separate. (c) Similar to (b) except that the load on the sheets has been increased so that the area of molecular contact is larger. ($\times 15$)



(b)



(c)

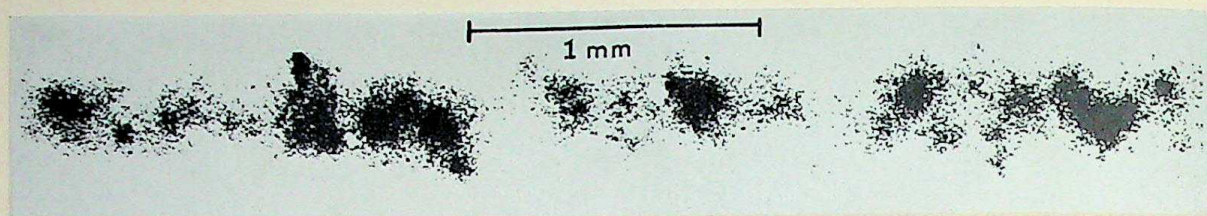


FIGURE 11 - Autoradiograph of copper transferred to clean steel surface when sliding at a speed of 0.01 cm/second under a load of 2 kg. The pick-up consists of small fragments and corresponds to about 10^{-6} g/cm of track.

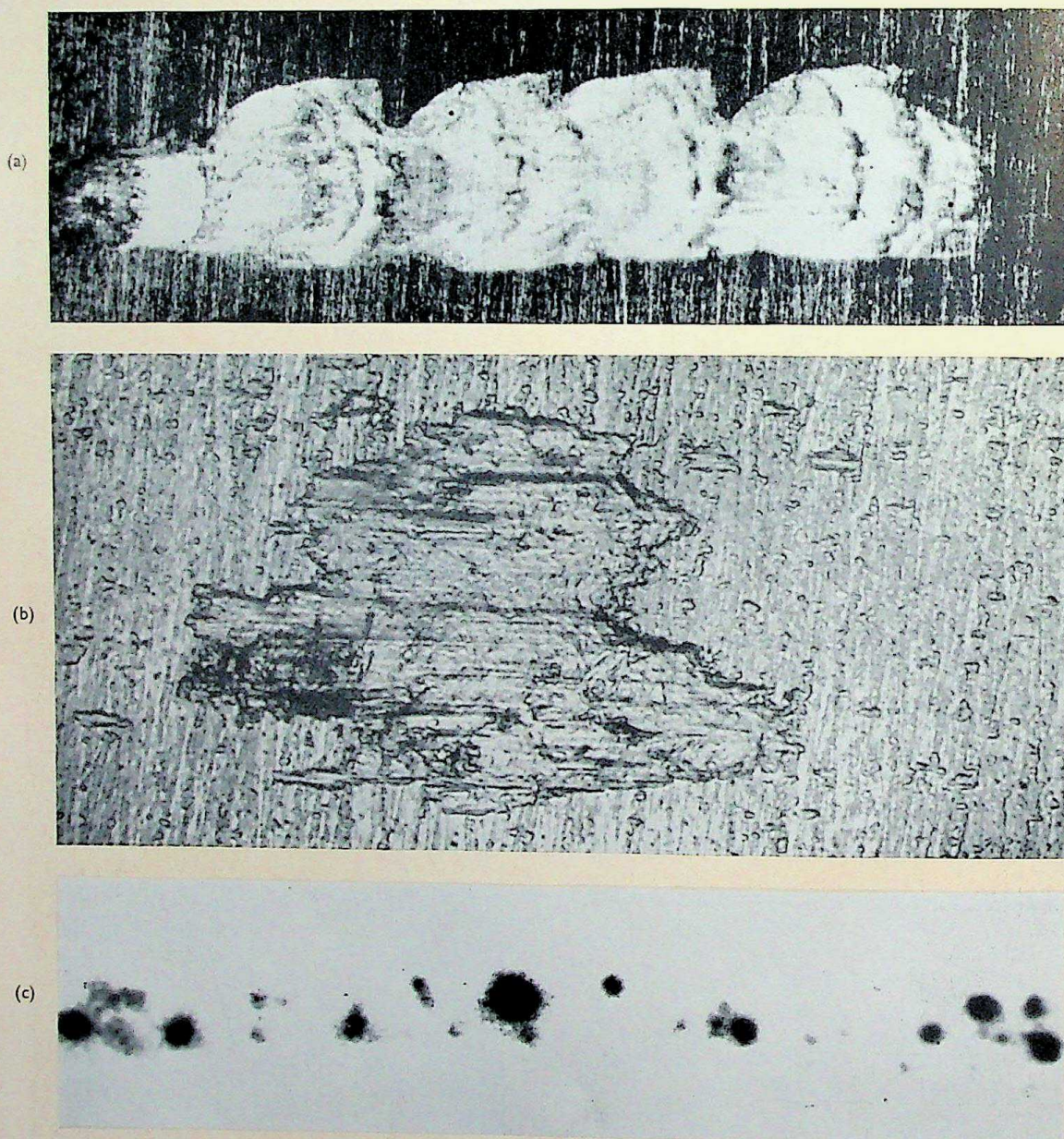


FIGURE 12 - (a) Track formed when polyvinyl chloride slides on itself. Mutual welding occurs ($\times 60$). (b) Track formed when polyvinyl chloride slides on steel. The plastic is welded on to the steel ($\times 400$). (c) Track formed when radioactive silver slides on polyvinyl chloride. Some metal (ca 3×10^{-8} g/cm of track) is transferred to the plastic. ($\times 20$)

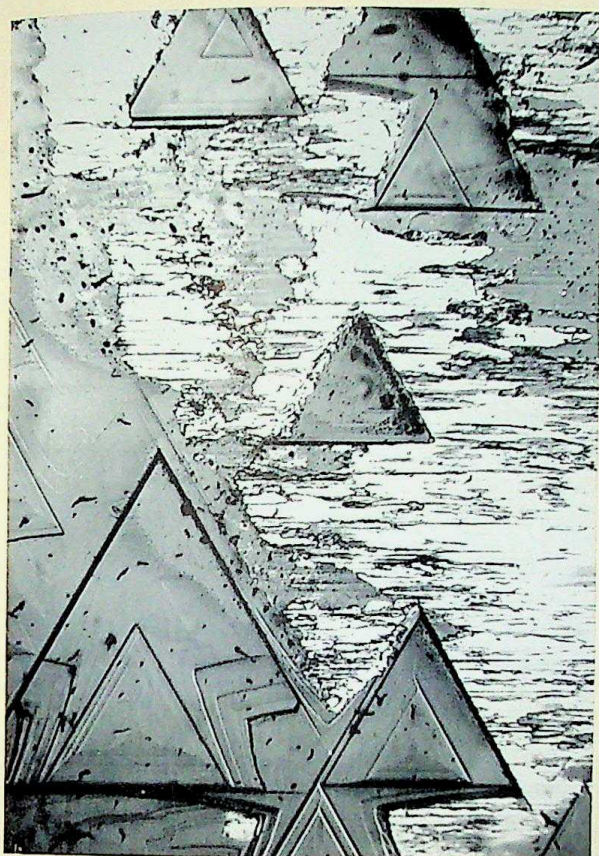


FIGURE 13 - (Left) Diamond rubbed at speeds greater than 250 m/sec. The diamond surface is undamaged and steel is smeared over it. The triangles (trigons) are a characteristic feature of the natural diamond face ($\times 170$). (Right) Diamond rubbed by steel at speeds just below 250 m/sec. The diamond surface is readily polished. ($\times 200$)

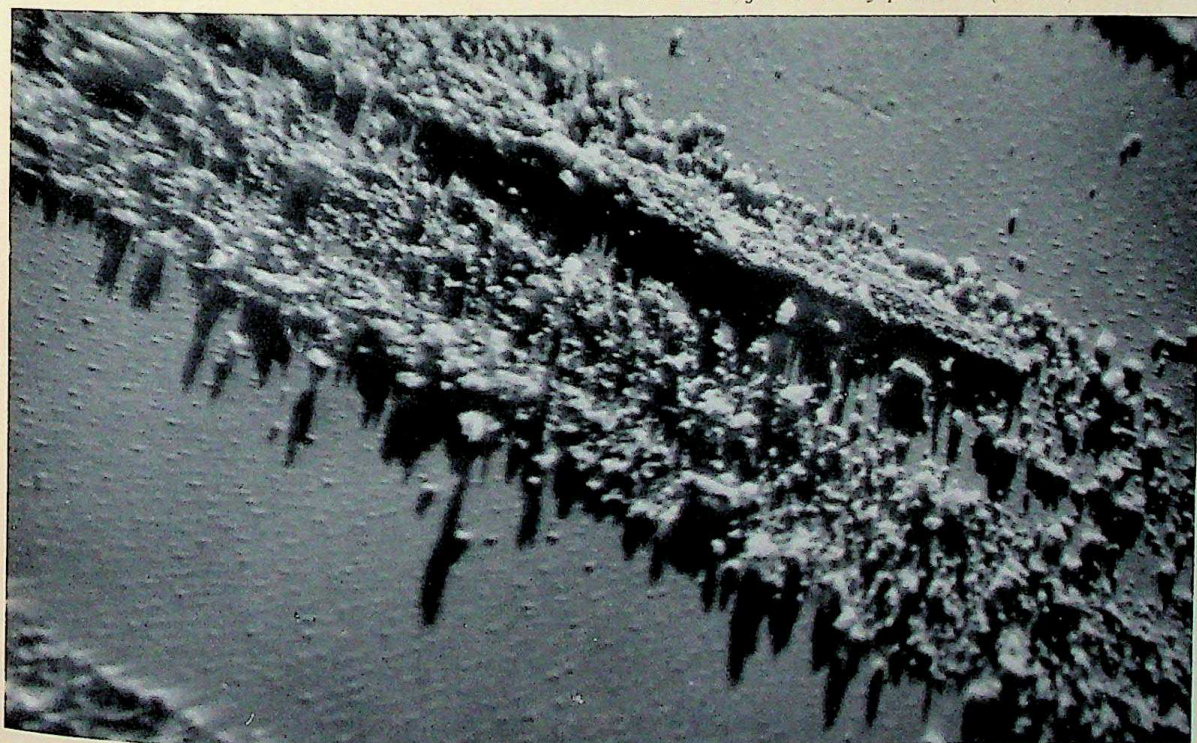
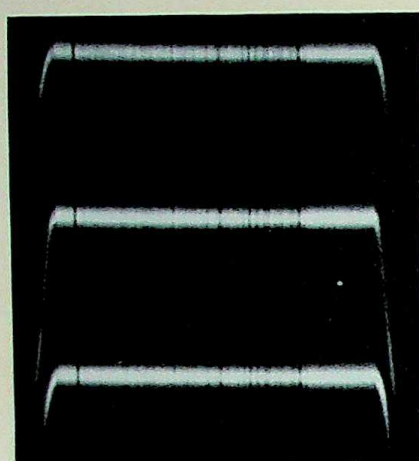
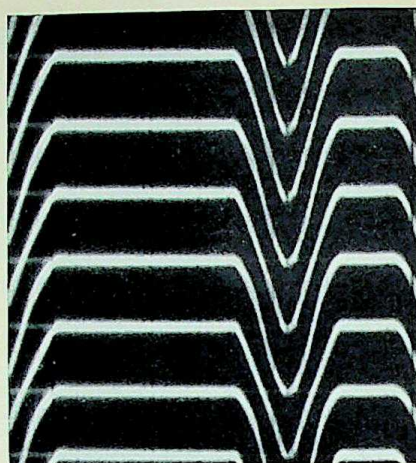


FIGURE 14 - Reflection electron micrograph of damage when molecularly smooth mica surfaces are placed in contact and slid. ($\times 4000$)



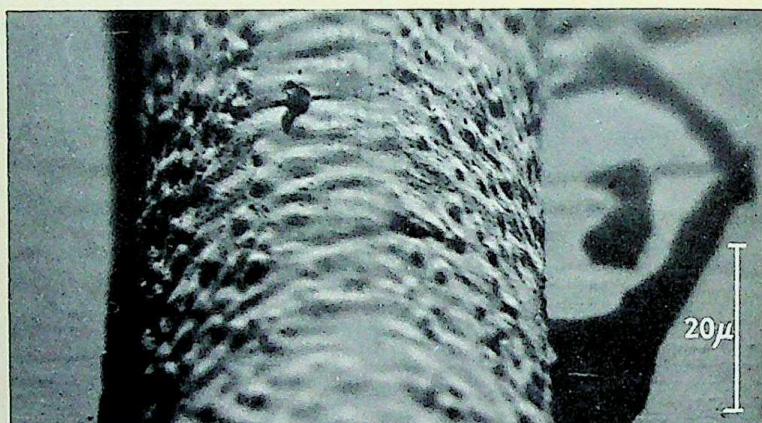
(a)



(b)

FIGURE 15 – Fringes of equal chromatic order used in the examination of the area of contact of mica surfaces. (a) When the surfaces are in molecular contact, the fringes are each of constant wavelength and flat. (b) The presence of a small irregularity is revealed by the deflection of the fringes (shown by arrow).

FIGURE 16 – Reflection electron micrograph of nylon fibre (diameter $50\ \mu$). The curvature of the 'cobblestones' is accentuated by the glancing incidence of the electron beam. Surface damage due to sliding can be seen.



and partly because of its high contact angle, in consequence of which it is not wetted by water: we may also expect that any hydrogen bonding of the water or the ice to the surface would be difficult. Experiments showed that it did in fact give a low friction under most conditions of sliding on snow and ice. The static friction at various temperatures of skis coated with a conventional ski lacquer, with a racing ski wax, and with P.T.F.E. is illustrated in figure 17. It will be seen that the friction for all these surfaces falls as the snow warms up and also that P.T.F.E. gives the lowest friction. Timed descents have also been made both with live skiers and with dead weights on the skis. Some typical results are given in Table IV.

Under all the conditions of our experiments the P.T.F.E. skis were appreciably faster. They are pleasant and easy to ski on because they give a low uniform friction, even when running on patchy snow. They should have useful applications not

only in skiing but also in sledging and in aircraft landing, particularly on very cold or very wet snow. They have been used recently with some success in the Antarctic for the landing and take-off of aircraft on difficult snow.

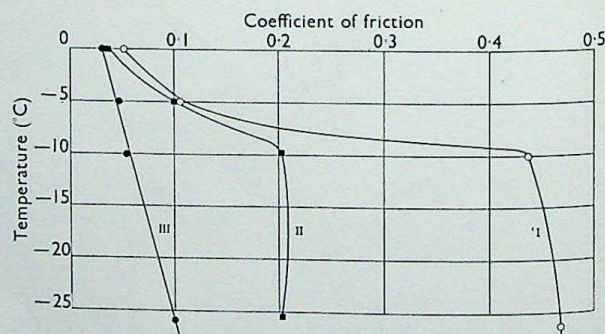


FIGURE 17 – Influence of snow temperature on the static friction of skis. Curve I: Ski lacquer. Curve II: Ski wax. Curve III: P.T.F.E. The friction is high at low temperatures and falls as the temperature approaches zero. P.T.F.E. gives a low friction at all temperatures.

FRICTION AND ADHESION OF
MOLECULARLY FLAT SURFACES

The conventional laws of friction are obeyed because the surfaces are never smooth, so that contact occurs only in local regions. If we could put molecularly smooth surfaces together the behaviour should be quite different. Recently A. I. Bailey and J. S. Courtney-Pratt [12] have been doing experiments of this kind. If good-quality muscovite mica is cleaved with great care the cleavage will often pass along a single plane in the crystal, so that it is possible to obtain sheets which, over an appreciable area, are molecularly smooth on both sides. The great difficulty in these experiments is to be certain that the surfaces are smooth and that over the region where they touch the contact is truly molecular. A minute particle of dust or a cleavage step on the mica which might only be 10 Å high would vitiate the experiment. S. Tolansky [13] has shown that multiple-beam interferometry is an elegant and powerful tool which can detect surface irregularities that are only 3 or 4 Å in height. Figure 9 shows a cleaved mica sheet under examination by this method. The different colours correspond to different thicknesses of the sheet, and over each region of uniform

colour the surfaces are molecularly flat. In Miss Bailey's experiments molecularly smooth sheets are selected, bent into cylindrical form, and mounted at right angles. The lower sheet is fixed to the stage of a microscope, while the upper is held up by four equal springs. A highly reflecting layer of silver is deposited on the top surface of the upper sheet and on the under surface of the lower sheet in order that multiple reflections should occur within the two sheets. The apparatus is designed so that normal and tangential forces may be applied and measured.

The contact region is approximately circular, and if the surfaces are within molecular distance the colour of this region will be uniform. In figure 10(a) a few minute irregularities of some kind (perhaps tiny dust particles) are present, and the surfaces are not in true contact. Particles or irregularities of this kind, which cause a separation of only a few Ångströms, are easily detected. In figure 10(b) the contact is molecular over the whole region. If the load on the mica sheets is increased, this area of contact becomes larger, and this is illustrated in figure 10(c).

The contact region may also be examined using fringes of equal chromatic order. This method, which is illustrated in figure 15, has the advantage that the absolute height of any irregularity can conveniently be measured. When the surfaces are in molecular contact the fringes are each of constant wavelength and appear straight (figure 15(a)). The presence of a small irregularity is revealed by the deflection of the fringes (shown by the arrow in figure 15(b)).

The adhesion has been studied by measuring the force required to separate these surfaces in a normal direction; in a slightly different experiment the work of separation is measured during the actual cleavage process (figure 18). The forces F are applied, as shown, to the ends of a piece of mica, causing it to cleave. The ends are held horizontally for experimental convenience.

TABLE IV

Timed descents: Comparison of waxed ski with 'new' ski (P.T.F.E.)

Series 1. Crystalline spring snow; air temperature 5° C; snow temperature zero; gentle slope of length 213 metres (tracked)

Weight on ski (lb.)	Time of descent (seconds)	
	Conventional ski with Norwegian wax and paraffin	'New' ski (P.T.F.E.)
168	61	42
140	83	54

Series 2. New snow fallen few hours previously; air temperature 10° C; snow temperature zero; unloaded ski (tracked)

Details of slope	Time of descent (seconds)	
	Conventional ski with ski lacquer	'New' ski (P.T.F.E.)
Gentle, 20 metres long	10	6
Steeper, 30 metres long	6	3

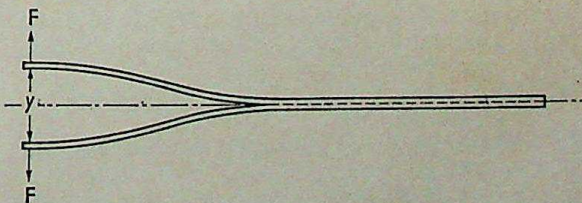


FIGURE 18—Method of measuring the work required to separate molecularly smooth mica surfaces. Forces F applied at the ends cause the mica to open by an amount which is determined by recording the movement of the line of bifurcation and the separation.

The force F and the distance y are measured at intervals as the cleavage proceeds. The corresponding positions of the line of bifurcation are recorded simultaneously, using the multiple-beam interference techniques. From the values of F and y the total work done in the process may be determined.

On first cleaving the mica the energy required is 300 ergs/cm². If the two pieces are allowed to come again into molecular contact and cleaved a second time, it is found that the mica is almost as strong as it was originally, the work necessary being 250 ergs/cm². This result is surprising, since one might expect that contact with the atmosphere would have resulted in the adsorption of gases and water vapour, with consequent loss in strength.

If the sheets are separated and a monomolecular layer of a fluorinated fatty acid is deposited on each, the sheets will still adhere when placed in contact. The work required to separate these layers may then be determined. As we would expect, the result yields a lower value, 155 ergs/cm². These values are estimates of the surface energy of the materials, since they determine the work necessary to create unit area of solid-air interface.

Using the apparatus incorporating the crossed cylinders, the force to shear the junction—i.e. the friction—can also be measured. Such experiments yielded the very high value of 10 kg/mm² for the shear strength of freshly cleaved mica surfaces in contact. The damage to the mica surface under these conditions is very great (see figure 14). Similar observations were made using sheets of mica on which a monomolecular film of the boundary lubricant had been deposited. The material used was calcium stearate deposited by the Langmuir-Blodgett technique, a monomolecular layer being placed on each sheet. The shear

strength obtained was then 250 g/mm², and the surface was undamaged. This result is useful in that it shows that when ordinary solids, lubricated with a boundary film, are slid one over the other, a considerable force is necessary to shear the film of boundary lubricant itself.

CONCLUSION

It is evident that there is a close connection between friction and adhesion. Friction is essentially the shear strength, and adhesion the tensile strength of the junctions formed at the region of contact. For most solids, whether they are plastic, brittle, or elastic, the surface adhesion can be strong. The differences in the frictional behaviour of various solids are due mainly to the difference in their mechanical properties, since it is this which determines both the area of real contact and the shear strength of the junction.

Materials which give a high coefficient of friction will potentially give a strong adhesion. Whether this adhesion will in fact be observed depends primarily on the effect of elastic stresses released when the load is removed. If these stresses can be avoided, or if their effects can be accommodated by the ductility of the junctions, the potential adhesion will be observed. If they cannot be eliminated, the observed adhesion may be very small indeed. Lubricants which reduce the friction by diminishing the amount of metallic contact produce an even greater reduction in the adhesion. Similar considerations are important in the action of practical adhesives.

ACKNOWLEDGMENT

This article is mainly an account of recent work by my colleagues and myself. I wish to thank Dr D. Atack, Dr A. I. Bailey, Dr D. M. Kenyon, Dr L. E. Raraty, and Mr M. Seal for assistance in preparing it and for permission to quote unpublished work. An account of background work, with appropriate acknowledgments, will be found in [1].

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Animal photosensitivity, with special reference to eyeless forms

N. MILLOTT

Many eyeless animals can respond to light in a variety of ways. Often the general body surface is sensitive to light, but the precise structures concerned in absorbing it, and the way in which they act, are unknown. The same kind of sensitivity may be present in animals with eyes. There are indications that the mechanism of reception is fundamentally similar to that of eyes, and the organization of the sensory system may become surprisingly complex.

Sensitivity to light is a common property of living matter. Though radiation of wavelength shorter than $3900 \text{ \AA}$ has profound effects on protoplasm, it plays no part in what are arbitrarily regarded as visual processes, and its effects are consequently beyond the scope of this account, which is concerned with the reception of waves in the range $3900\text{--}7600 \text{ \AA}$. Most animals possess complex eyes for photoreception; these eyes have a highly differentiated receptive surface or retina, often associated with a lens system for concentrating and focusing the light. Eyes, however, are not the sole means of photoreception. Not only are simpler equivalents, the so-called 'eye-spots', often involved, but the general body surface may be sensitive to a remarkable degree, and it is this form of light perception which is our special concern here.

Little is known of the visual processes of animals other than vertebrates, a few arthropods, and squids. Consequently we have little idea of the evolution of vision. Again, our knowledge of how a complex eye works remains very incomplete, and since there are indications that the process of photoreception depends on a pattern of activity that is fundamentally the same over a wide range of animal forms, the quest for a common denominator may yield important information.

This common pattern consists of the following processes: (1) The absorption of quanta of light energy, which raises the energy level of the capturing molecules. This has been termed primary photoreception, and it occurs in the photoreceptor. Because visible light is absorbed, an appropriate pigment must be present, and this determines the relative sensitivity of the animal to various regions of the spectrum. Photoreceptive areas have often been recognized by virtue of this pigmentation. (2) The excitation of some mechanism coupled to the last, by means of which electrical changes are

produced, possibly by a rapid rearrangement of reactive chemical groups, resulting in ionic movements. (3) The transfer of excitation along specialized conducting channels (in cellular animals, the nerves).

Excitation is conducted to an 'effector', either directly, or via analysing, correlating, integrating, and controlling nerve centres, so that the animal becomes aware of light or reacts to it. The reaction, though a terminal event, is an indicator of the effect of light, and unless special analysing methods are used it is the only one available.

In the simplest protozoans neither specially differentiated light-absorbing structures nor specifically involved pigments have yet been identified. In others, even at this level of non-cellular organization, there is a tendency for the photoreceptive area to become localized as eye-spots, sometimes involving dioptric apparatus. There is still some doubt as to whether the light absorbed by the eye-spot pigment is directly concerned in excitation, or whether the pigment acts as a light filter for the real receptive area, which is ill defined. Since in many cases the colour of the eye-spot implies absorption of light of the same wavelengths as are found to be effective in exciting the animal, some workers have held that the eye-spot is in itself the photoreceptor; others maintain that it merely increases the uniformity and rapidity of the responses to light. It is most significant that carotenoids, possibly combined with protein, are present in the eye-spot (p. 27).

The effect of light may be direct and local, causing changes in the thickness and elasticity of the plasmagel and affecting the rate of its change into plasmasol, thereby affecting movement. Alternatively, it may affect the speed and direction of movement by modifying the action of locomotor organelles, so that co-ordination and the

conduction of excitation are involved, though little is known of any special apparatus for the purpose, or of how it functions. Responses may be shown to light of unchanging direction or to changes in intensity. Some animals (e.g. *Stentor*) respond to increases, others to decreases, and still others to both (e.g. *Volvox*).

In the vast array of cellular animals tendencies seen in the Protozoa appear again and may be carried further. Localization and specialization of photoreceptive areas result in highly complex eyes, but the direct local effects of light and the general diffuse sensitivity persist to a surprising degree even in relatively highly evolved forms, such as amphibians. Light acts directly and locally in some chromatophores. Diffuse sensitivity appears as the dermal light sense or dermatoptic sense. This appears in almost all phyla, and the early work has been reviewed by W. A. Nagel [1].

The character of the response to light varies greatly. It may be localized and isolated, or general and integrated, involving the whole animal. In the latter category are included the withdrawal reactions of such forms as hydroid polyps, sea anemones, tubicolous worms, and sea cucumbers. Photokinesis (locomotion in a variable direction with respect to the light source) is seen in lampreys, hagfishes, and blinded catfish. Phototaxis (locomotion in a constant direction with respect to the light source) is seen in brotulid and cave-dwelling fish. Tropistic movements (directed by light) occur in sessile organisms such as hydroids or tubicolous worms.

Responses of individual organs to light have been recorded a great many times. Often they appear to be localized manifestations of the withdrawal reactions mentioned above. Noteworthy instances occur in the molluscs *Pholas* (figure 14) and *Mya*, where there is retraction of the siphon in response to light, and in the tunicate *Ciona* (figure 9), where there is closure of the siphonal apertures; these responses form the basis of S. Hecht's classical studies [2, 3]. It is among echinoderms that such indicator responses appear most strikingly: the myriads of organs endowed with considerable independence—such as spines, pedicellariae and podia—respond individually or in co-ordinated groups. Some of the podial responses of the sea urchin *Lytechinus* are shown in figures 19–21. The responses of the spines of the sea urchins *Centrostephanus* (figure 4) and *Diadema* (figure 2) have been examined in detail by J. von Uexküll [4] and N. Millott [5] respectively. Individual systems may respond to light. For example,

reproductive systems may respond by ovarian and testicular activity, ripening of germ cells, and spawning. Gametes may respond to light by tactic movements or by fusing, and primordial germ cells by maturation. Many animals show both integrated and local responses.

The type of response may be related to the kind of stimulus. Kinetic responses result from steady illumination, tactic and tropistic responses from similar but directional light, and there are localized responses to changes in intensity. These may be given to increases of intensity only, for example by the bivalve mollusc *Psammobia* or the feather star *Antedon*; or to decreases, as in sea cucumbers such as *Holothuria*, *Thyone*, or *Synapta*, starfish such as *Asterias* and *Cribrella*, in tubicolous worms such as *Branchiommia* (figure 10), and in bivalves such as *Cardium* and *Pinna*. Responses to both increases and decreases appear in molluscs such as *Chiton* and *Mactra*, as well as in echinoids such as *Diadema* and *Centrostephanus*.

Such indications of photosensitivity are unhappily the only ones available until electrophysiological methods have been applied. With such drastic limitation it is not surprising that there is little reliable evidence of the precise structures, or even areas, concerned in dermal photoreception. Until electrophysiological methods have shown nerve impulses arising from photostimulation of dermal receptors, the demonstration of the dermal light sense cannot be regarded as complete.

Within this confine the most direct demonstrations have been obtained using localized stimulation by means of small light patches. By this method Millott [5] has shown that the entire surface of *Diadema* is light-sensitive, but not uniformly so. D. R. Newth and D. M. Ross, using larger light patches, found a somewhat similar condition in the hagfish. The so-called 'eyes' of *Diadema antillarum* have the appearance of, and behave like, iridophores (figure 15, ir.). The precise status of the eyes in *Diadema setosum* has several times been questioned. Much the same applies to the terminal tentacles of echinoids and organs assumed to be specialized photoreceptors in a variety of animals; thus the pigmented spots previously called ocelli, around the siphonal openings of *Ciona* (figure 9), are in fact not light-sensitive. In tube worms and starfish the situation is ambiguous. The ocular spots on the tentacles of the branchial crown of *Branchiommia* are not essential for the animal's most characteristic response to changes in light intensity, and in starfishes the function of the eyes is far from clear. The great majority of investigators

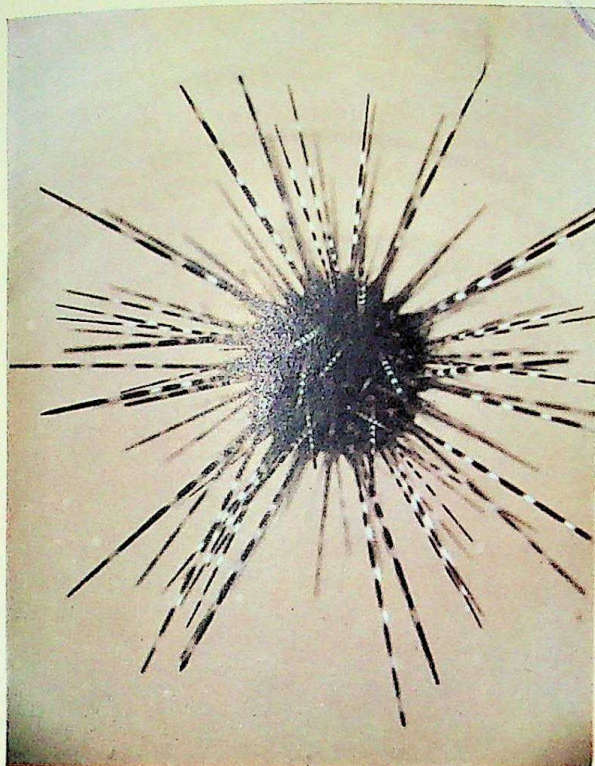


FIGURE 1 – *Diadema antillarum*. Young individual in the light-adapted condition when melanin is dispersed over the light-sensitive surface and sensitivity to shadows is diminished.

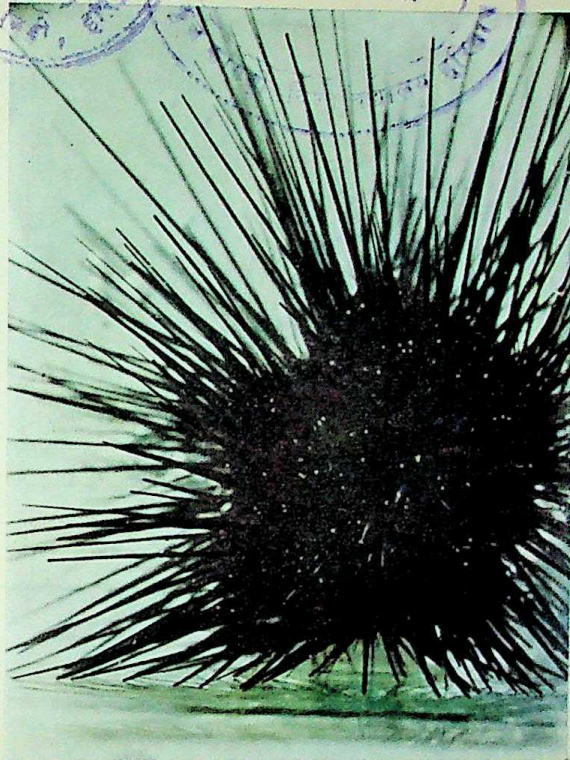


FIGURE 2 – *Diadema antillarum*. Adult, showing the spines which are moved vigorously towards shading objects.

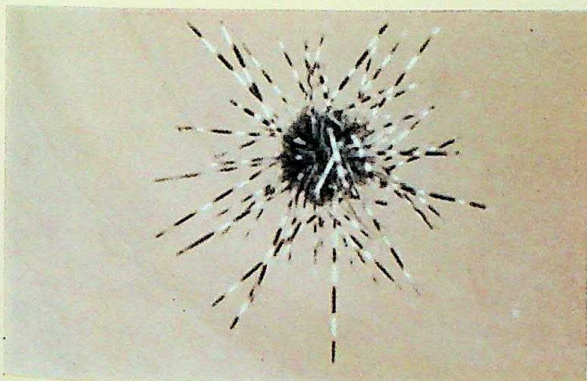


FIGURE 3 – *Diadema antillarum*. Here the animal is paler in colour due to concentration of melanin, exposing the light-sensitive surface of the test, so that sensitivity to shadows is increased.

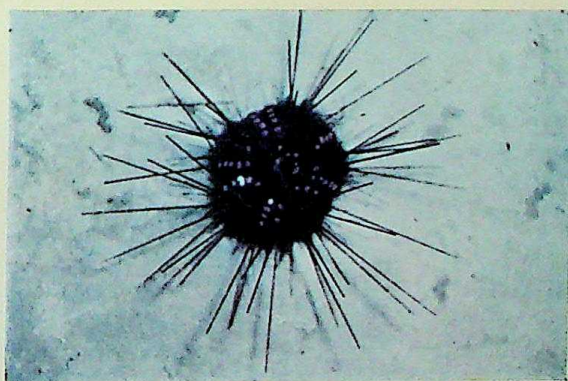


FIGURE 4 – *Centrostephanus longispinus*, which also shows well marked spine movements and colour change in response to changes in light intensity. The extensive pigment appears to serve as a light screen.



FIGURES 5 AND 6 – *Lytechinus variegatus*, showing the covering reaction. Figure 5 (left) shows the urchin with its covering removed. Figure 6



shows the urchin as it usually appears in shallow sunlit waters, covered by debris, including shells of bivalve molluscs, held in position by the podia.

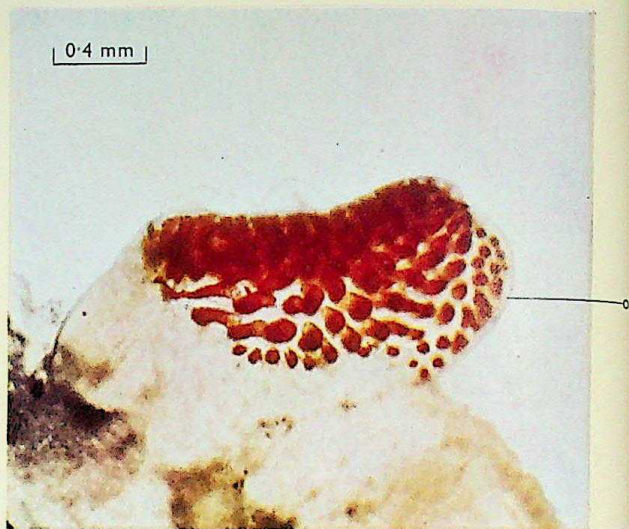
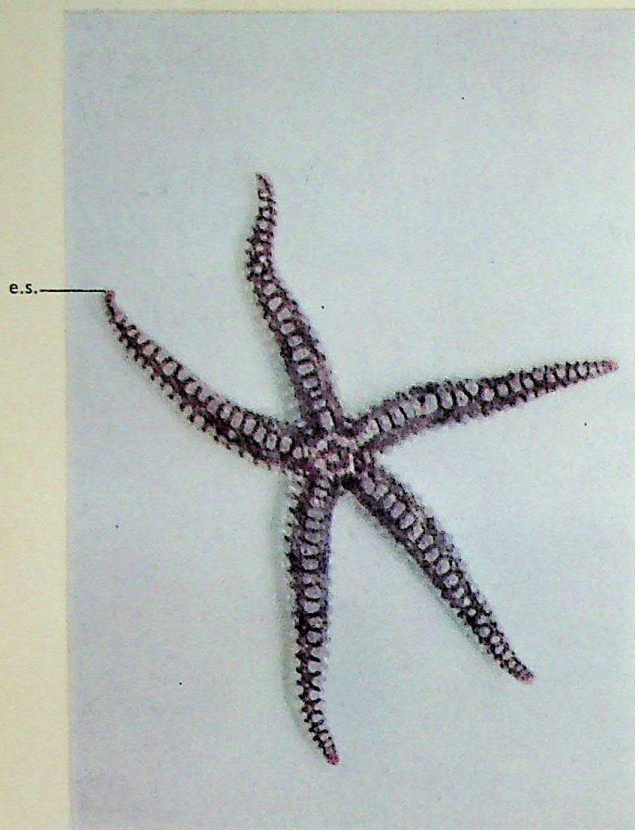


FIGURE 7 – *Marthasterias glacialis*. The excised eye-spot (optic cushion), showing the optic cups (o.c.), the prominent colour of which is due to β -carotene and esterified astaxanthin.

FIGURE 8 – (Left) *Marthasterias glacialis*, showing the position of the eye-spot (e.s.); one is present at the tip of each arm. Some colour of the body wall is due to the same pigments as those in the eye-spots.

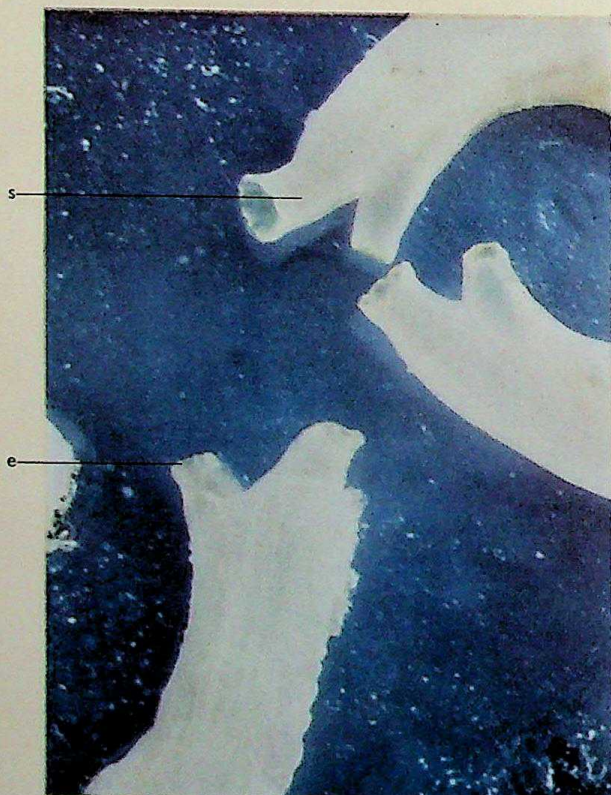


FIGURE 9 – *Ciona intestinalis*, which responds to light by retraction of the siphons (s). The so-called ocelli (e) are not sensitive to light.

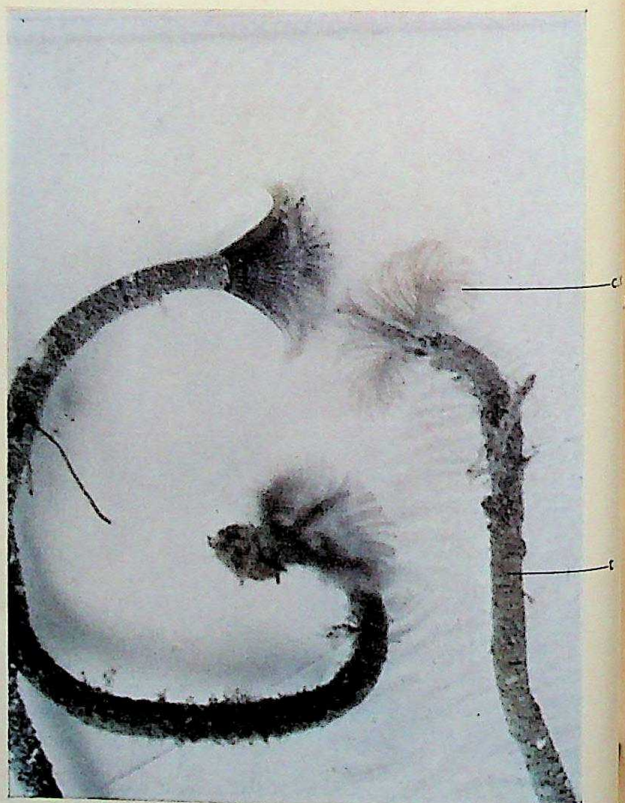


FIGURE 10 – *Branchiomma vesiculosum*, which withdraws into its tube (t) in response to shadows, showing the light-sensitive crown of tentacles (c.t.).

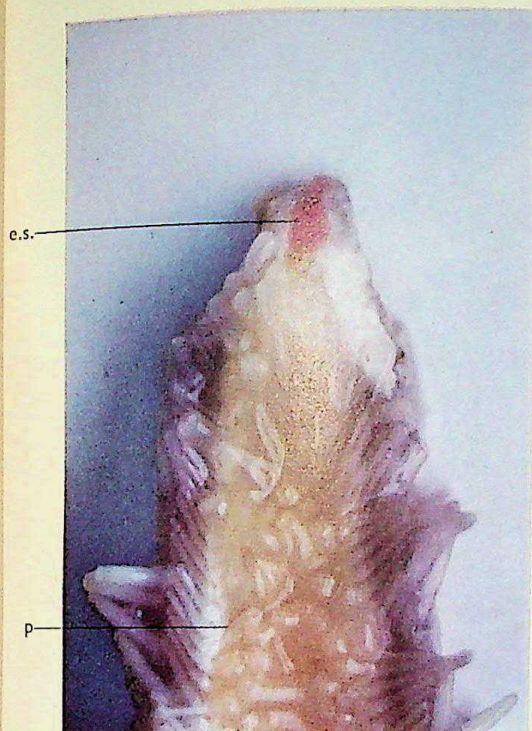


FIGURE 11 – *Marthasterias glacialis*; the lower (oral) surface of one arm tip, showing the eye-spot (e.s.), revealed by removing part of the surrounding body wall. p, podia.



FIGURE 12 – Part of a transverse section of the ammocoete larva of lamprey, showing the light-absorbing melanin (m) which shields the central nervous system (n.t.). nch., notochord.

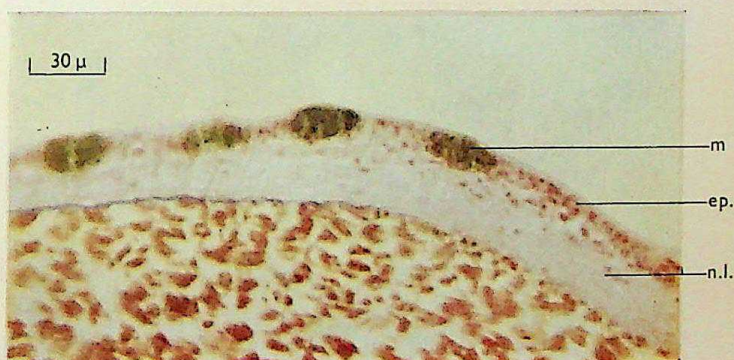


FIGURE 13 – *Diadema antillarum*. Part of a section of a spine base, showing the melanophores (m) which shield the superficial nerve layer (n.l.). ep., epidermis.

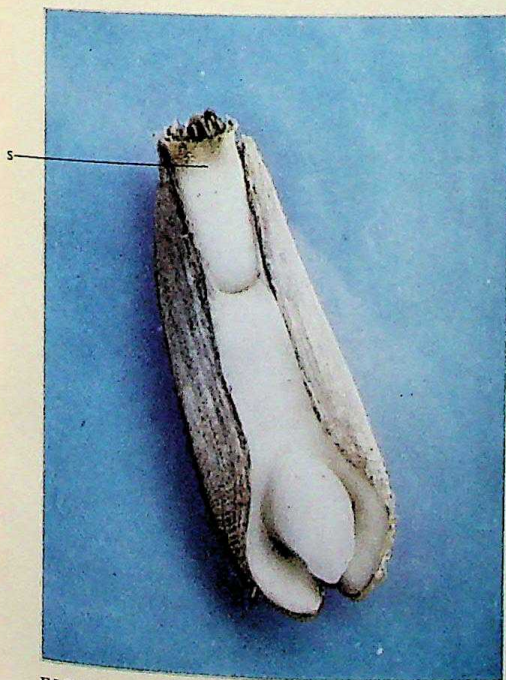


FIGURE 14 – *Pholas dactylus*, showing the siphon (s) which is retracted when stimulated by changes in light intensity. The entire surface is stated to be light-sensitive.



FIGURE 15 – *Diadema antillarum*. Section of the region between two spine bases, showing two iridophores (ir. and ir'). s, epidermis covering outer surface.

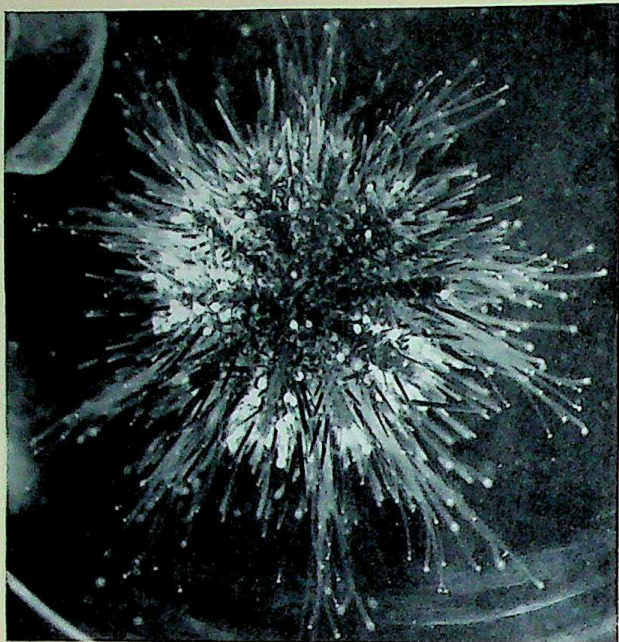


Figure 17

FIGURE 16 - (Left) *Lytechinus variegatus*. Young individual, showing the extended podia which pick up covering from the surroundings and hold it so as to shade the aboral surface. The white tips of the podia are suckers.

FIGURES 17 AND 18 - *Lytechinus variegatus*. Two stages of the covering process. Figure 17 shows two extended podia attached by their suckers to a mollusc shell (bottom left). The tips of the sea urchin's spines are seen at top right. Figure 18: A later stage, showing the shell, together with two similar ones, after being pulled on to the spines by the podia. Additional tube feet have been applied to the shell.



Figure 18

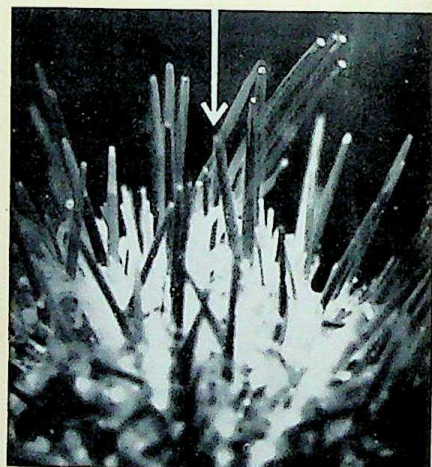


Figure 19

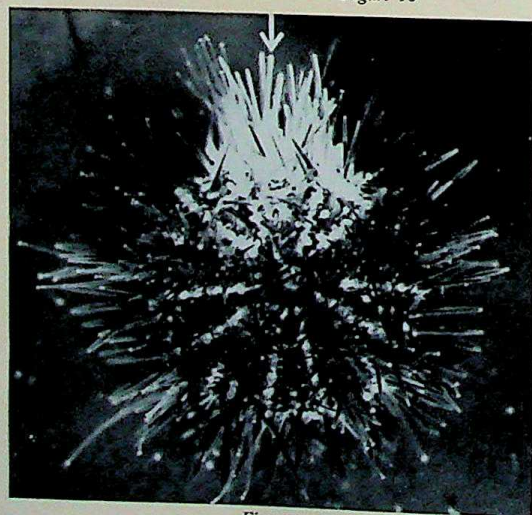


Figure 20

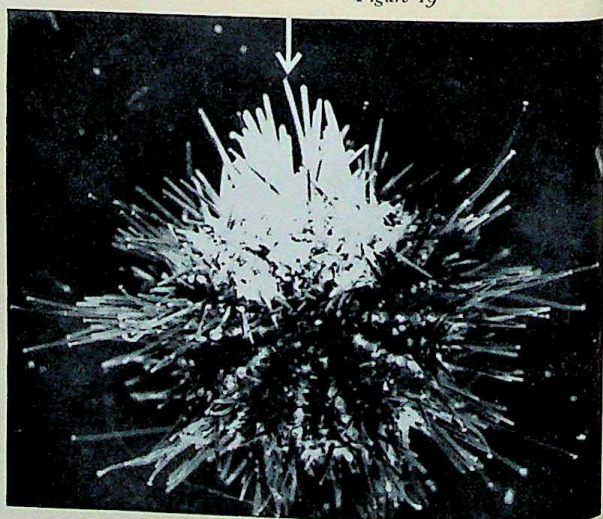


Figure 21

FIGURES 19-21 - *Lytechinus variegatus*. Reactions of the podia to light. Figure 19: Extension of the tube feet following a decrease in light intensity. The tube feet in the light beam (directed along the arrow) were photographed while still extending in response to a brief interruption of the light.

20: Extension of the podia (identifiable by their white terminal suckers) immediately after transfer from dim light to a steady beam, directed along the arrow. Figure 21: After 30 minutes, the podia in the light beam having failed to reach covering, are withdrawn, while the remaining podia are still extended.

agree that the skin of various starfish is light-sensitive, but the eyes (figures 7 and 11) have been described in *Asterias* and *Solaster* as essential for phototactic responses (though for *Asterias forbesi* this has recently been denied), while they are stated to be unnecessary for orientation in *Echinaster* or in *Asterina*. Apart from their function in orientation, the eyes of an unspecified species of *Asterias* have been convincingly shown to be genuine and sensitive to light by the exquisite technique of H. K. Hartline [10], who recorded the electrical impulses in the eye-spot following light stimulation. Here dermal sensitivity co-exists with differentiated eyes, a condition that exists in other forms, particularly insects, where the eyes are much more elaborate.

Apart from the eyes, the photosensitivity of the general body surface may show some differentiation. Thus in various molluscs showing such diffuse sensitivity the mantle edge, tips of the siphons, and pallial gills are most sensitive. In some tubicolous worms sensitivity is confined to the tentacles (figure 10), the distal quarter of which is more sensitive than the rest. In cyclostomes, either anterior or anterior and posterior regions of the body are most sensitive. In fishes the posterior regions are the most sensitive. In the acorn worm *Ptychodera*, as in the earthworm, the anterior tip of the body is most sensitive. In some starfishes an interesting differentiation has been described: the podia and skin gills are stated to be particularly sensitive to steady light, while the body surface is said to be sensitive to changes in intensity. In sea cucumbers such as *Synapta*, on the other hand, the whole surface is sensitive to both. In *Holothuria surinamensis* the whole surface is sensitive to shading, but the rim of the cloaca is particularly sensitive, the posterior end and tentacles are less so, and the podia are the least sensitive.

By attempting to correlate the differential distribution of sensitivity in the body surface with histological structure, efforts have been made to identify the precise structures concerned in photoreception. In earthworms and in the bivalve *Mya* the sensitive regions embody special cells with lens-like organoids which are prolonged into nerve fibres, the whole apparatus appearing to be a photoreceptor. In the skin of lamprey larva, scattered, apparently sensory cells, containing what appears to be a carotenoid protein, have been described by D. Steven. Their wide distribution and pigmentation (see below), together with some features of dark adaptation, suggest that these structures may be involved in photoreception.

Crozier has suggested that pigmented cells in the skin of *Holothuria surinamensis* may be photoreceptors. In general, however, localization of sensitivity is too ill defined to be of much use in this way, and in all these cases the necessary proof—the electrophysiological demonstration of photosensitivity—is still clearly needed. While the quest for this vital information continues, it may not be inappropriate to note that many investigators have sought for histologically defined or obviously pigmented structures. Such differentiation is not essential, however; for, setting aside the limiting factor of technique, biochemical organization need not necessarily result in visible histological differentiation. Much the same argument applies to the preoccupation with obvious pigments, for the simpler protozoans react effectively to visible light without obvious pigment, and the masterly biochemical analyses of G. Wald [6] and his associates, together with the similar physiological analyses of R. Granit [7], W. A. H. Rushton, and others, indicate that even in some highly complex eyes little photosensitive pigment is directly required for excitation and, so far as can be seen at the moment, most of it constitutes a store.

The photosensitivity recently described in the echinoid *Diadema* [5] has shown that there is a remarkable correspondence between sensitivity distribution and that of nerve elements, both superficial and deep seated. Although, like the previous findings of J. Z. Young in the lamprey, this does not furnish proof, it clearly suggests that such elements themselves may perhaps be excited directly by light. Such an idea is unorthodox, for it is widely assumed that light perception systems mean the existence of integral, morphologically specialized, photoreceptors. Such a direct effect on nerve does not seem improbable, however, for excitatory processes in photoreceptors, nerve cells, and fibres all have a similar electrical manifestation. Further, it could at once explain the prevalent dermal photosensitivity of echinoids, since in these so much of the nervous system is spread out just below the surface. There is no demonstration of such a property in echinoderm nerves, but there are indications that nervous structures other than specialized photoreceptors are excited by light in other animals; examples are the sixth abdominal ganglion of crayfish and lobsters, the genital ganglion of *Aplysia*, and nerve elements in the brain of lampreys, minnows, and ducks. In the first two instances, electrical activity resulting from the action of light has been recorded.

Indications of a different kind derive from

experiments in which nerves, for example those of frogs and crabs, have been rendered light-sensitive by dyes. These experiments must, however, be interpreted with caution. It may be that they reveal the existence of a potential sensitivity to light in such nerves, which normally may merely lack a suitable light absorber. On the other hand, the eosin dyes used in these experiments have long been known to produce in living matter effects that are essentially destructive. These effects resemble photosensitized oxidations, especially of —SH groups (so-called 'photodynamic action'), and differ fundamentally from normal photosensitized processes in living matter (see H. F. Blum [8]). A study of diffusely photosensitive animals has already opened what may be a new vista on this fundamental problem, for the sea urchin *Lytechinus* (figures 5 and 6), which normally covers itself when in strong sunlight, may be induced to do so in relatively weak light by injections of photodynamic dyes such as eosin Y and rose bengal. As will be clear from figures 17–21, the covering response is complex, involving reactions of the podia to steady, continuous light (figures 20 and 21) and to changes in intensity (figure 19). As a result of these co-ordinated reactions, shells, pieces of debris, etc., are lifted from the immediate surroundings and held like sunshades over the light-sensitive surface. In this case the injected dye photosensitized a normal, complex, and co-ordinated chain of events.

Despite the large number of observations, there have been few serious attempts to analyse, in thermodynamic terms, the mechanisms underlying the dermal light sense. The classical studies made by Hecht [2, 3] on *Giona* and *Mya* still remain the basis of such analyses. Recently Newth and Ross, and Steven, have analysed the photokinetic reactions in cyclostomes.

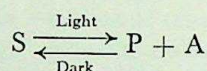
Hecht conceived two main processes resulting from the action of light: an initial photochemical process, uninfluenced by temperature and showing some conformity to the reciprocal time-intensity relationships prescribed by the Bunsen-Roscoe law; and a succeeding 'dark' process, conforming to reactions of the thermal type. A study of the relations between the intensity of the applied light and the interval between its application and the beginning of a reaction (reaction time), together with changes in sensitivity undergone in darkness, led him to postulate the following fundamental relationship for a given intensity:

$$\text{Reaction time} = \text{sensitization period} \\ + \text{latent period.}$$

The sensitization time is the minimum time for which the animal should be illuminated in order to bring about a reaction.

On a basis of these relationships and their temperature characteristics—together with variation of sensitization time with the reciprocal of the intensity, the ability of the animal to attain sensory equilibrium at any intensity, and the change in reaction time after a period in darkness—he postulated reactions of the following type as the fundamental processes underlying sensitivity to light.

1. A bimolecular photochemical reaction in which a photosensitive substance S decomposes in light, yielding the products P (a precursor of S) and an accessory substance A. P and A recombine to form S in the primary 'dark' reaction:



2. One or both of the substances P and A is assumed to catalyse a secondary 'dark' reaction in which an inert substance L changes into an active substance T, which stimulates the sensory nerve.

Hecht was well aware of many shortcomings in his scheme, which he advanced deliberately in the simplest possible concrete form. Thus he pointed out that reaction (1), though for convenience presented as reversible, is in reality probably more complex and not strictly reversible. In (2) catalysis by the products of photolysis was suggested as one possible means of producing T, but other means were envisaged, including combination of L and a product of photolysis.

The two 'dark' reactions were regarded as consecutive, but Newth and Ross, on the basis of their findings in hagfish, suggest that they are contemporaneous, or overlap. Steven, working on the same animal, noted that the responses to light consist of an initial, sometimes local, response and later of swimming. He accordingly suggested that in hagfish two levels of excitation are involved, and that these are responsible for the double response. Extensive studies by Wald and his associates have revealed the need for much greater elaboration if the scheme is to remain applicable to events in retinae, where the regeneration of the photosensitive substances has been shown by them to be a complex process involving both energy-absorbing and energy-yielding reactions, as well as a light-sensitive isomerizing enzyme.

Crozier suggested that in the sea cucumber,

Holothuria surinamensis, both the products of the photolytic decomposition of a skin pigment, and changes in its concentration brought about by changes in light intensity, stimulate nerves.

Von Uexküll's studies on *Diadema* led him to postulate that the reflex reactions to light and shade were initiated by the decomposition of a photosensitive purple skin pigment into substances which stimulate nerve endings. The nerve pathways, and much of the mechanism involved in reactions to light and shade, were conceived as being different. This scheme involved several highly original concepts for which it is hard to find exact physiological equivalents, and it has never been resurrected.

The reactions to both increases and decreases in intensity recall the 'on' and 'off' responses well known as part of the retinal and optic nerve discharge pattern. In view of this it would not be surprising if the differences between responses to increase and to decrease in light intensity were to prove to be due, at least in part, to correlatory mechanisms in the nervous system.

A cardinal feature of any light-perceiving mechanism is the nature of the absorbing pigment, since its specific absorption is a decisive limiting factor in sensitivity. In consequence the degree of sensitivity in various spectral regions may help in identifying the pigments. Though the pigments present in many kinds of eyes have been identified, we have no direct evidence of the nature of the pigments involved in the dermal light sense. It would appear that identification may prove difficult, as in many cases, judging by the total absence of colour to the human eye, they are present in small amount; again, in some sea urchins (figure 2) they are masked by relatively large quantities of skin pigment such as melanin, which plays no known direct part in vision. It is understandable that many investigators should have sought clues in eyes, in even the simplest of which the pigments are more concentrated. Many eye pigments have been identified, chiefly in vertebrates, but also in some arthropods and in squids. A striking feature is that many are carotenoids. One of them, astaxanthin, is also present in the parts of plants exhibiting phototropism. The close association of these pigments with photosensitivity is clearly indicated by their spectral absorption, which follows closely the spectral sensitivity of the animals in which they occur. A fairly close correspondence between the spectral regions most evocative of indicator responses in some animals perceiving light by means other than eyes, and the regions

of the spectrum most strongly absorbed by these known visual pigments, suggests that the same kinds of pigments may be involved. Thus the spectral sensitivity of *Mya*, *Ciona*, *Pholas*, and *Lam-petra* has been shown by Steven to be compatible with the absorption of vitamin A derivatives of the rhodopsin-porphyrin type. It is wise to be cautious in identifying photosensitive systems with particular compounds, for in carotenoid proteins absorption varies with both prosthetic and protein moieties, and, as H. J. A. Dartnall [9] has pointed out, many physical factors must be taken into account in making adequate and valid comparisons between absorption and spectral sensitivity.

Other indications have come from studies of the pigments in the skin and eye-spots of starfishes. Thus in *Marthasterias* (figures 7 and 8) the prominent pigments of both are β -carotene and esterified astaxanthin, but it would be premature to draw definite conclusions from such observations, since the eye-spots of *Marthasterias* have not yet been shown to be photosensitive. Nevertheless, a similar condition exists in *Asterias forbesi*, where both skin and eye-spots contain photosensitive, but as yet unidentified, pigment; as already mentioned, a response to light in the eye-spot of one species of *Asterias* has been demonstrated conclusively by Hartline. The early accounts of what were assumed by von Uexküll to be pigments of the visual purple type in tropical sea urchins can be discounted, for he did not characterize them chemically and the evidence of their participation in light perception is wholly inadequate.

Pigments not directly implicated in vision may play a significant indirect role as shielding and filtering pigments in light-sensitive surfaces, both in eyes and elsewhere. The results obtained by H. F. Blum and D. L. Fox, who studied the spectral sensitivity of the flagellate *Dunaliella*, suggest that such pigments may be present even in Protozoa, and carotenoids such as astaxanthin may function in this way in the complex eyes of crustaceans. Melanins, by virtue of their strong light absorption and the nature of their histological distribution, have often been suspected of acting as a protective shield for light-sensitive structures. Thus in lampreys such pigments in the skin and around the spinal chord (figure 12), as already shown by Young, are effective in shielding the light-sensitive central nervous system and lateral line nerves. The significance of melanin in the dermal light sense of the young forms of *Diadema* where the pigment participates in a colour change has been

shown by Millott [5] (figures 1 and 3). The sensitivity to changes in light intensity, using both locomotion and spine responses as indicators, varies with the degree of dispersion of melanin in the skin. As a result, light-adapted phases (dark in colour, figure 1) and dark-adapted phases (pale in colour, figure 3) can be recognized. The dark-adapted are more sensitive. The melanophores lie (*m*, figure 13) immediately to the outside of the superficial nerve layer (*n.l.*), a position that explains how dispersion and concentration of pigment can seriously influence the intensity of light penetrating the skin. Such controlling mechanisms recall those sometimes attributed to the melanin in the retinas of some crustaceans, insects, and vertebrates, the concentration and dispersion of which form part of the so-called 'photomechanical movements' in these eyes.

Some sea urchins which live in shallow sunlit waters possess no such striking amounts of shielding pigment. One such species, *Lytechinus variegatus* (figure 5), is highly sensitive to light, and covers itself extensively with debris (figure 6), an action which is initiated by relatively strong light. This suggests that in doing so it compensates for lack of screening pigment.

In comparing the general organization of a dermal photoreceptor system, such as that of *Diadema*, with that of a complex vertebrate or arthropod eye, certain parallels appear. The responses to changes in light intensity recall the 'on' and 'off' responses in the optic discharge pattern. In each, the primary photoreceptor mechanism is associated with accessory pigments, the disposition of which can vary so as to alter the amount or pathways of incident light. Further, the melanin in young *Diadema*, as in some eyes, shows a diurnal rhythm of dispersion and concentration. Many complex eyes contain reflecting elements forming a tapetum, apparently for the purpose of reflecting and diffusing light of low intensity over the receptive surface; their counterparts appear in the iridophores of *Diadema* (*ir.*, figure 15) which diffuse light over the general body surface (*s*) and may

thereby significantly increase the capacity of the urchin to respond in dim light.

Such complexity of organization is rather surprising and may be a reflection of the importance of the dermal light sense. Where eyes are lacking or inadequate such a sense is sufficient, when steady light forms the stimulus, to ensure that the possessor attains the conditions of illumination best suited to its mode of life: by swimming, as in lampreys; by burrowing, as in hagfish; by withdrawing exposed parts of its body, as in some crayfish and lobsters; or by covering, as in *Lytechinus*. When changes in intensity form the stimulus, the sense is adequate to ensure withdrawal from a stimulus of increased lighting or from shadows that may signal a harmful change, or presence, in the near vicinity. The sense is also sufficient to ensure movement toward shading objects, as may occur in the podial reactions of *Lytechinus* (figure 19) in capturing pieces of covering, or in the defensive spine movements of sea urchins.

The dermal light sense has often been described as primitive, and regarded as a survival of the ancient sentient surface, from which specialized photoreceptors have arisen by concentration and localization. That this has occurred there can be no doubt, but such a view can be interpreted in a dangerously simple fashion, and it should not be overlooked that some stages of such a process have occurred at the protozoan level. It is now also evident that a fairly elaborate organization can be attained without much concentration and localization. This suggests that sensitivity to diffuse light may have been redeveloped at various evolutionary levels. Existing knowledge carries us no further, but its paucity at least serves to emphasize the need for much further investigation.

ACKNOWLEDGMENT

The author acknowledges with thanks permission he has received from the following to reproduce some of the illustrations: Dr G. Bras, University College of the West Indies (figures 1 and 3); Mr G. Underwood, University College of the West Indies (figures 5 and 6); Dr M. J. Wells, *Stazione Zoologica*, Naples (figure 4).

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The early history of the vacuum pump

E. N. DA C. ANDRADE

The attainment of a high vacuum is an essential part of many modern processes in research and industry. For the atomic particle accelerators; for the huge atomic plants; for metal refineries; for factories where all forms of electric lamps, valves, television tubes, and such-like are made—for all these, and many others, great vacuum installations are essential. All this, however, is the creation of the last fifty years or so, mainly as a result of the inventive research of Gaede. What is here described is the history of the vacuum pump before these modern developments.

At the beginning of the present century the methods used for producing vacuous space were very much those of a century earlier. In tracing the history of the vacuum pump, then, we have a natural boundary separating the old instrument and plaything of the natural philosopher, with which great discoveries were accomplished, and the modern creation of the physicist-engineer, without which the atomic revolution could not have been effected.

The first man to produce a vacuum deliberately and to realize clearly what he had done was Torricelli, a student of Galileo's. Galileo in the First Day of his *Dialogues* had drawn attention to the fact that a pump could not draw up water

through a height greater than 18 braccia (which seems to have been about 1060 cm, a comfortable margin above the limit in fact attainable). He had also established that air had weight, but certainly did not at the time connect the weight of the atmosphere with the height of the water column. Torricelli in 1644 described his famous experiment in a letter to Michel Angelo Ricci. What concerns us here is the development of the Torricellian method to produce a vacuous space for experiment; this was carried out by the *Accademia del Cimento* and published in its *Saggi di Naturali Esperienze* in 1667.

The top of the barometer tube was enlarged, and access to this space was provided by an opening which could be closed by a sheet of bladder, suitably supported. In such a space significant experiments were carried out. It was shown, for instance, that the magnetic force was the same in vacuo as in air; that smoke, produced by heating a small ball of bitumen with sunlight focused by a mirror, fell in vacuo; that a lamb's bladder, squeezed out and tied so as to contain only a little air, swelled out to a sphere in vacuo (figures 1(a) and 1(b)). This method of producing a vacuum, which was used long after by Rumford, can be considered as the application of a one-stroke mercury pump, and the experiments achieved are distant forerunners of those carried out with the Geissler and Töpler pumps some two hundred years later. They were, of course, subsequent to the invention of the airpump by Guericke and to the earliest airpumps of Boyle, now to be

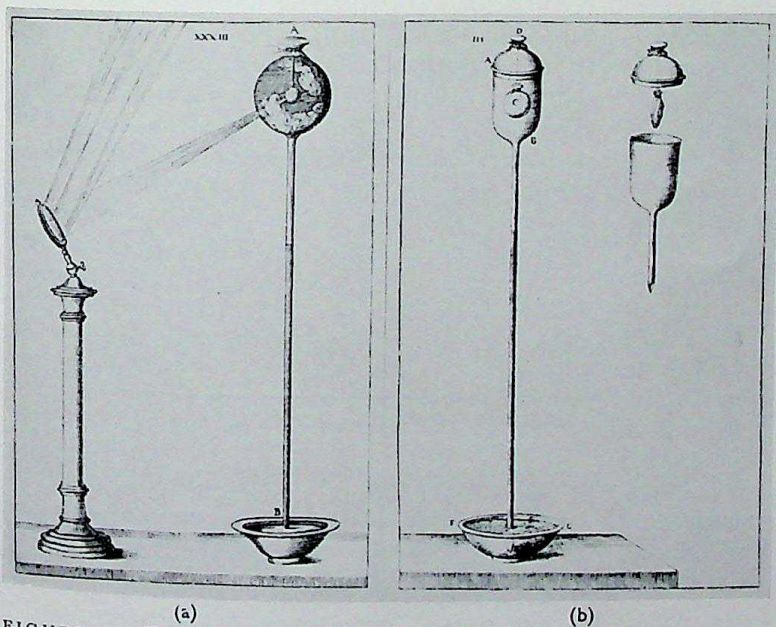


FIGURE 1 — Experiments carried out by the *Accademia del Cimento* with the Torricellian vacuum. (a) shows smoke falling in vacuo; (b) a lamb's bladder, containing a little air, swelling in vacuo. In both cases the top of the experimental vessel is closed with bladder, but in (b) the bladder is carried by a glass lid, to which no reference is made in the text. In the English translation quoted the right hand figure in (b) is omitted.

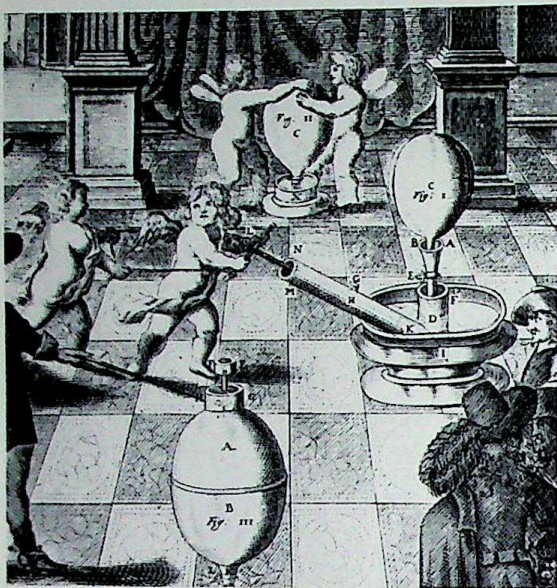


FIGURE 2 – The first representation of a vacuum pump, from the description of Guericke's early work in Schott's *Mechanica Hydraulico-Pneumatica*.

described, but, as is said quite truly in the *Saggi* when Boyle's 'curious and noble Experiments' are cited, '... the Vessel can never be emptied so perfectly by that way, as by Mercury.'¹

It was Guericke, of course, who first produced an airpump in the sense of a machine by which any space could be progressively evacuated to the limit which leaks and vapour pressure imposed. The exact date of his first successful attempt is uncertain. Guericke himself, who was born in November 1602, gave a comprehensive account of all his work in his *Experimenta Nova (ut vocantur) Magdeburgica de Vacuo Spatio* (The New, commonly called Magdeburg, Experiments on Empty Space) in 1672, long after it was carried out. The famous Magdeburg experiment was, however, cited much earlier and the pump described, with Guericke's sanction and approval, by the Jesuit Kaspar Schott, a very active writer on scientific subjects, in his *Mechanica Hydraulico-Pneumatica* (1657), the book which was the first occasion of Robert Boyle's interest in the airpump. The experiment was actually carried out in 1654, in the presence of the Emperor and princes assembled at Magdeburg for the imperial diet at Regensburg.

In this celebrated demonstration two copper 'Magdeburg hemispheres', about 50 cm in diameter,² were used, fitted with iron rings to which teams of horses could be attached. They were

¹ Quoted from the translation by Richard Waller, published in 1684.

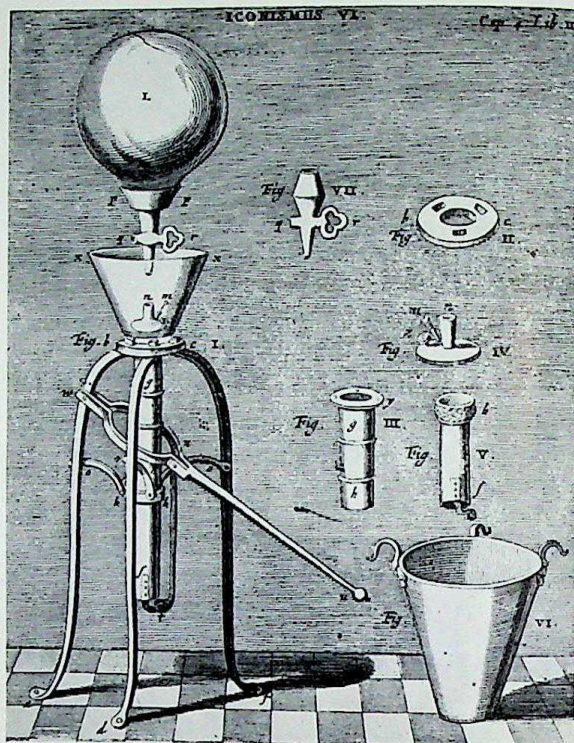


FIGURE 3 – Guericke's pump, as figured in *De Vacuo Spatio*.

placed together so as to form a sphere, the joint being made airtight by means of a leather washer soaked in wax and turpentine. When the enclosed space was exhausted, two teams of eight horses failed to bring them apart: it would require a pull of about 1.5 tons to do so. Guericke also carried out the experiment with hemispheres about 70 cm in diameter.

The airpump figured by Schott is shown in figure 2, which is the first representation of a vacuum pump ever published. It is described as having two valves, one at H, half-way along the sloping barrel of the pump, G being an opening, and the other at the lower end of the barrel, at I.

² Guericke says that the hemispheres were three-quarters of a Magdeburg ell in diameter 'or (because the artificers do not make vessels exactly as requested), 67 hundredths of a Magdeburg ell'. As I had some difficulty in finding the length of this ell, I may mention that the value is given in the *Encyclopédie Méthodique*, Section Commerce (Vol. III, p. 165, 1784), as 295.6 French lines, there being 144 French lines to the Paris foot, which was 1.066 English feet. This makes the Magdeburg ell 67 cm, so that we can take the diameter of the Magdeburg spheres as roughly 50 cm. All the histories of science consulted by me record the diameter in Magdeburg ells. As only the rough measurement of the spheres is of interest, these details may seem finical unless it is remembered that the ell varied from 114 cm in England to 56 cm in Leipzig, to take familiar ells only.

No detail is given of these valves, but we are told that the one at I opens inwards towards I and is closed towards D—by which is to be understood that it opens when the piston is withdrawn and closes when it is pushed in—while that at H opens outward to the air under internal pressure and closes when the pressure falls. This positioning of the valves is clearly not a very efficient one, and Schott says that the in-and-out motion (*agitatio*) of the piston has to be continued for two, three, or more hours, according to the capacity of the receiver C. The cherubic lab boys in the background have placed an exhausted receiver nose-down in water: Schott records that when the tap was opened the water would shoot in with a great rush and tumult, as if boiling. The tap E could be used to shut off the evacuated vessel. It was, apparently, with such a pump that the Magdeburg experiment was carried out.

The final form of Guericke's pump, as represented in *De Vacuo Spatio*, where it was first described, is shown in figure 3. It bears many resemblances to Boyle's pump, and it is most probable that Guericke had seen Boyle's book, of which a Latin edition appeared in 1661, although he nowhere refers to Boyle. The vertical cylinder *gh* was supported by a tripod: it is shown separately at 'Fig. III'. A lead washer was used at the top to make an airtight fit. The piston, shown at 'Fig. V', was of wood, with a string packing. To let out the air a leather valve *z*, closed by a spring ('Fig. IV'), was provided. This worked during the early stages: when the air pressure became too small to force it open, the hand-operated peg valve *m* was used. The operation of the tap *qr* and the valve *m* was as in Boyle's pump and will be described when this is considered. The conical vessel *xx* at the top of the cylinder and the other one shown at 'Fig. VI', which was hung so as to enclose the lower end of the cylinder, were to contain water for the purpose of rendering the various joints airtight. The receiver was of glass, cemented to the brass attachment which carried the tap.

Boyle first described his airpump in '*New Experiments Physico-Mechanicall Touching the Spring of the Air*', published in 1660. He says here that he had heard of, but had not perused, the book by the industrious Jesuit, Schottus, telling how 'that ingenious Gentleman *Otto Gericke*, Consul of *Magdeburg*, had lately practiced in *Germany* a way of emptying Glass Vessels, by sucking out the *Ayr* at the mouth of the Vessel, plung'd under water'. The pump, as Boyle freely acknowledges, was

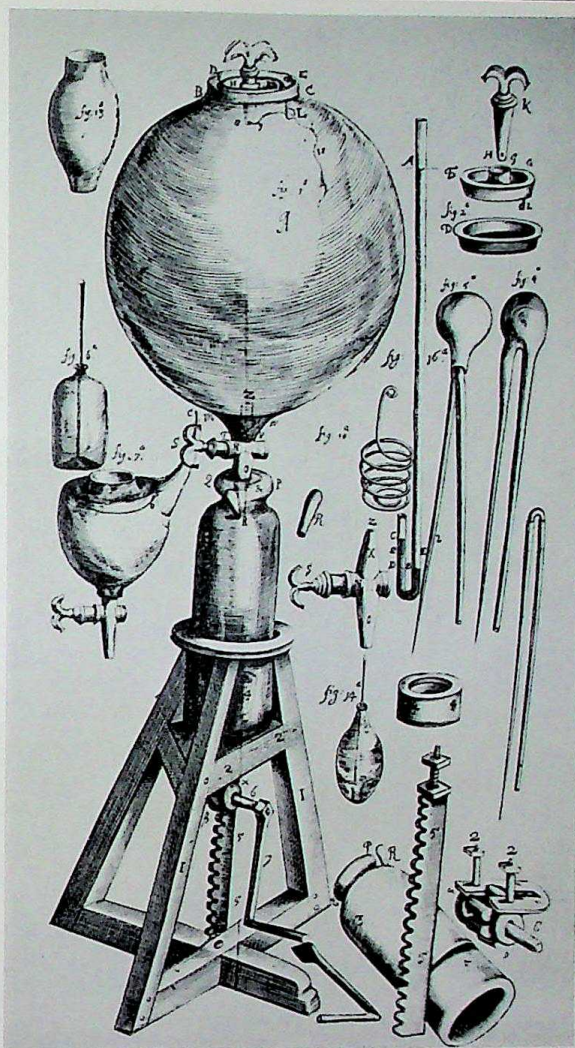


FIGURE 4—Boyle's first pump, made by Robert Hooke.

made by Robert Hooke, employed by him at that time as an assistant, and bears the stamp of his genius in design.

This pump, shown in figure 4, comprised a hollow brass cylinder of about 3 in. internal diameter, in which ran a 'sucker', presumably of wood, since a disk of leather was nailed to it, fitting the cylinder tightly. It is shown as 4, 4, above the detached ratchet. On to this sucker, moved up and down by a rack and pinion, oil was poured to make for easy running and an airtight fit, but Boyle records that a mixture—an emulsion, we should say—of oil and water often proved better. A stout wooden frame held the cylinder vertically. The receiver was a large glass sphere, of some 25 litres capacity, which was, we are told, the largest size that the glass-men could make of the requisite thickness. A great advantage that it

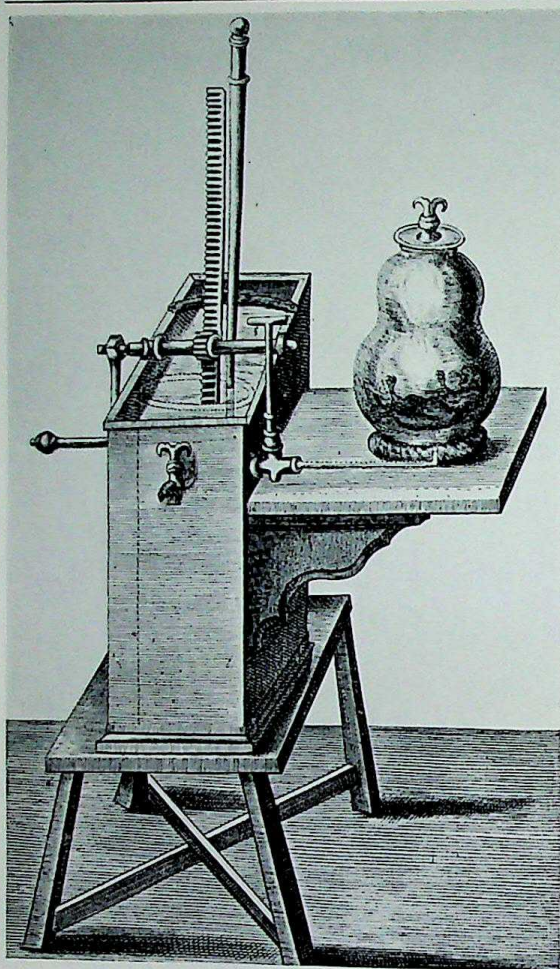


FIGURE 5 - Boyle's second pump.

possessed was the opening at the top, into which was cemented a brass ring, adapted to receive the accurately fitting cover shown in detail at the top right-hand corner of the figure. The small hole at the bottom of the plug K was provided for suspending objects in the receiver. This excellently contrived receiver greatly facilitated the carrying out of experiments in vacuo. That Guericke did not adopt it may have been due to inability of his craftsmen to execute it satisfactorily. To the bottom of the receiver was connected a brass fitting, provided with the tap S.

The shoulder of the cylinder was pierced by a hole closed by an accurately fitting brass valve-plug, shown separately at R. The mode of operation was as follows: with the tap closed and the valve-plug withdrawn, the piston was moved to the top of the cylinder, expelling the air through the hole. The hole was then closed with the plug, the piston withdrawn, and the tap opened, so that

part of the air in the receiver rushed into the cylinder. The tap was closed, the valve-hole opened by the withdrawal of the plug, and the process repeated. This was the method adopted by Guericke in his last pump, but he added the subsidiary valve, opened by the air-pressure, for the early stage of the pumping. The rack and pinion, the easy access to the receiver, and the general design and execution, which rendered the use of water to seal the joints unnecessary, make Boyle's pump much the superior instrument.

Boyle's second pump, described by him in 1669, is shown in figure 5. The great advantage was that the receiver was a bell-jar cemented to a flat plate by a mixture of beeswax and turpentine, a composition used in vacuum work until well into the present century. It could thus be easily removed and replaced for experimental purposes. The pump was a single cylinder submerged in the water bath shown: the piston itself was pierced by a hole which could be opened and closed by means of a plug on the end of the long stick shown protruding well above the water. The tap is shown on the pipe leading to the bell-jar. Boyle admits that, while having the pump submerged keeps the sucker 'turgid and plump' so that it remains airtight, the arrangement is not without its inconvenience.

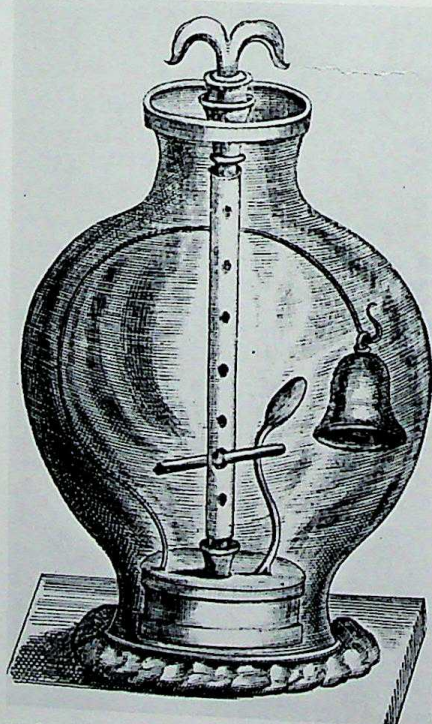


FIGURE 6 - Boyle's apparatus for showing that sound does not travel in vacuo.

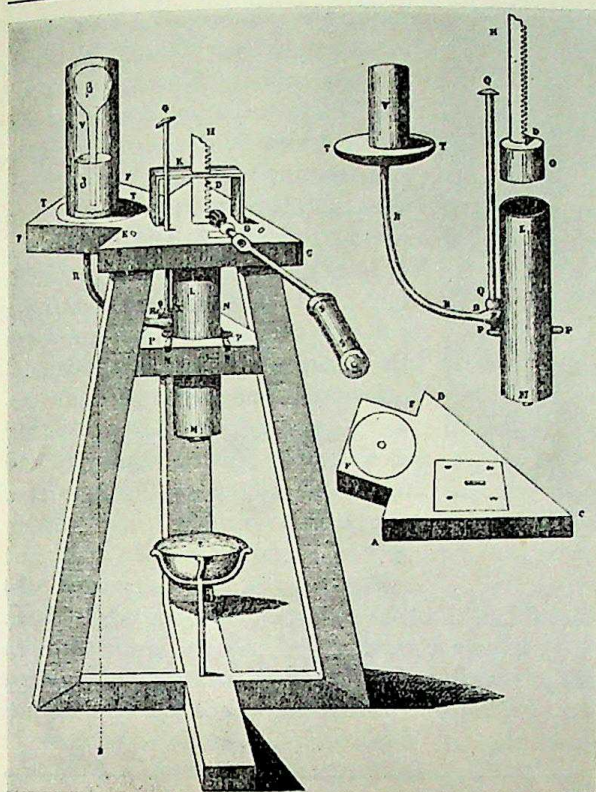


FIGURE 7 - The pump made by Papin to Huygens' pattern.

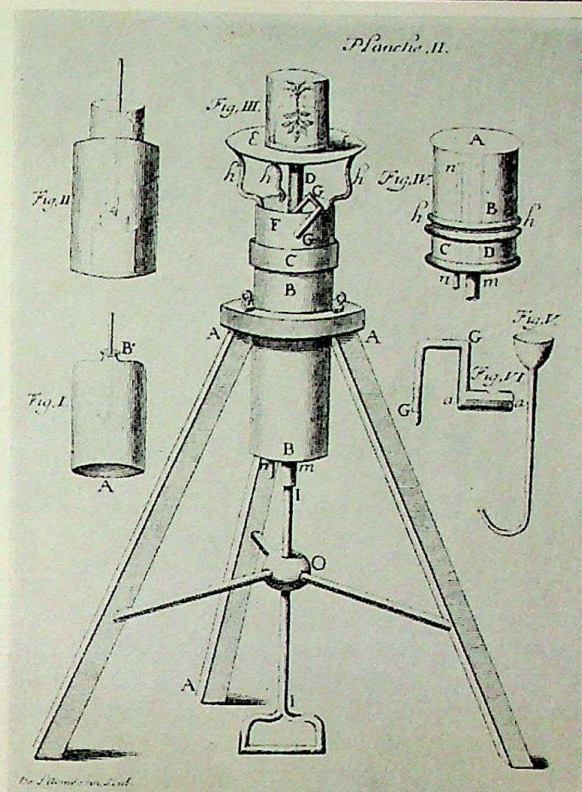


FIGURE 8 - Papin's pump, with two-way tap.

It must be remembered that Hooke, who made the first pump, had left the service of Boyle in 1662, and so, presumably, had no part in the making of the second. It is to this that the retrograde step of immersing the pump in water can probably be attributed; it seems likely that, without Hooke's craftsmanship, the airtightness of the piston could not be secured without this submersion. The use of water is the more surprising since, in his account of the first pump, made by Hooke, Boyle says that he wanted a pump 'that might not, like the other [Guericke's], need to be kept under water (which on divers occasions is inconvenient) and might be more easily managed'. This is an early example of the influence of technical accomplishment on design. As typical of the manipulation in vacuo we can take the disposition, whose mode of action is obvious, for striking a bell enclosed in the receiver, shown in figure 6.

Denis Papin, a genius who, like Hooke in his early days, often had to earn his living by assisting other and wealthier men, was in 1674 working with Huygens. The Dutch discoverer had seen Boyle's first pump in England when he was there in 1661 and on his return to Holland had, as we know from his letters, made a pump on the pattern

of Boyle's: it had, however, the great advantage of a flat plate, to which a bell-jar was applied to constitute the experimental space. He thus anticipated Boyle in this feature, although he published no account of it. Huygens, in Paris at the time, set Papin to make an airpump of his pattern, which was described in Papin's first publication, *Nouvelles Expériences du Vuide*, 1674. It is represented in figure 7. The piston was worked by a rack and pinion, as in Boyle's pump. One valve was a small hole at M, which was open when the piston descended to expel the air and covered by the finger when it ascended, the connection of the cylinder with the receiver being governed by the tap at F, which was controlled by the handle Q (right-hand detail, figure 7). The piston was made airtight with tow soaked in water, oil being then poured on from above. A plate was provided for the receiver, and a water gauge. The whole was very solidly mounted.

This was a version of Huygens' pump: in the same publication Papin described an improved form, shown in figure 8, for which he was entirely responsible. In this the control of the opening was affected by a two-way tap, shown at 'Fig. VI', one channel being an ordinary bore-hole, for

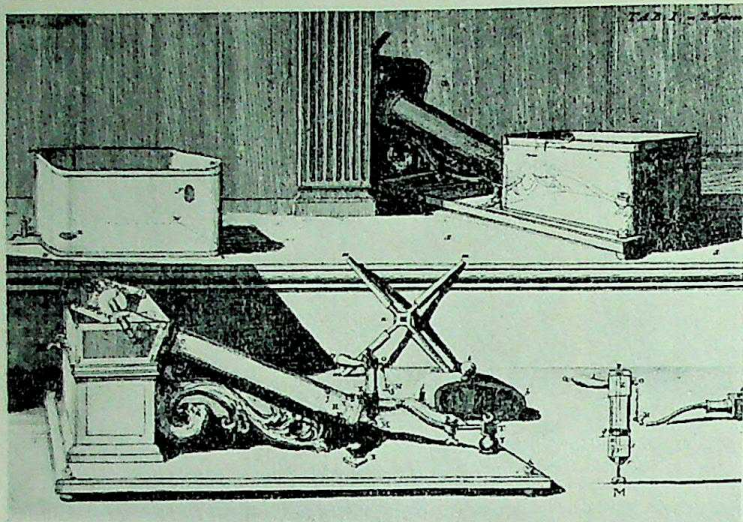


FIGURE 9 – Senguerd's pump.

communication with the receiver, and the other a groove along *aa*, for communication with the air. Papin is thus responsible for the invention of the two-way tap, usually attributed to Wolfert Senguerd, who used it in the pump to be next described. The tap in Papin's pump must have been well made, for he found it unnecessary to cover it with water. Another feature of this pump was the stirrup for applying the considerable force necessary to withdraw the piston against the atmospheric pressure.

Wolfert Senguerd's pump, which was much used on the Continent, was first figured in his *Philosophia Naturalis* of 1681, but figured again in more detail in the second edition of this book (1685), where it is very fully described, strangely enough in the preface '*Ad Lectorem*'. Figure 9 is taken from the plate in this preface: further on in the book there is a less detailed representation. Nearly all the German histories of physics, from J. C. Fischer (1802) onwards, say that while the pump was described by Senguerd in 1685 it was not actually made until 1697, and quote as authority Senguerd's *Rationis atque Experimentiae Connubium*, of 1715.¹ Here, however, the author says '*atque ut mihi construeretur, Anno 1679 cum Artifice conveni*' ('and I arranged with the artificer to have it constructed for

me in the year 1679'). I can only suppose that the first of the historians miscopied 1679 as 1697 and that the others copied him. The mistake is the more remarkable as the engraving gives every sign of having been made from an actual pump.

In Senguerd's pump the barrel is fixed in an oblique position and a two-way tap, shown separately on the right of figure 9, was used to alternate connection with the receiver and with the air. The full description says that, to prevent air leaks, the tap and lower part of the pump may be immersed in water, as shown in the upper part of figure 9. Once more is indicated

the difficulty at the time of making airtight joints.

Pumps of the Senguerd pattern were made in large numbers by the famous Dutch instrument maker Jan van Musschenbroek at Leyden, so that examples occur in most collections of historic

¹ The German authorities refer to this as the third edition. It is actually the first and only edition. On the title page, after *Rationis atque Experimentiae Connubium*, with details of the contents, and the author's name, with his titles, stands *Accedit Ejusdem, Disquisitio de Tarantula, Tertio Edit.* The *Tertio Edit* refers to the disquisition on the tarantula only, not to the main book which is here in question.

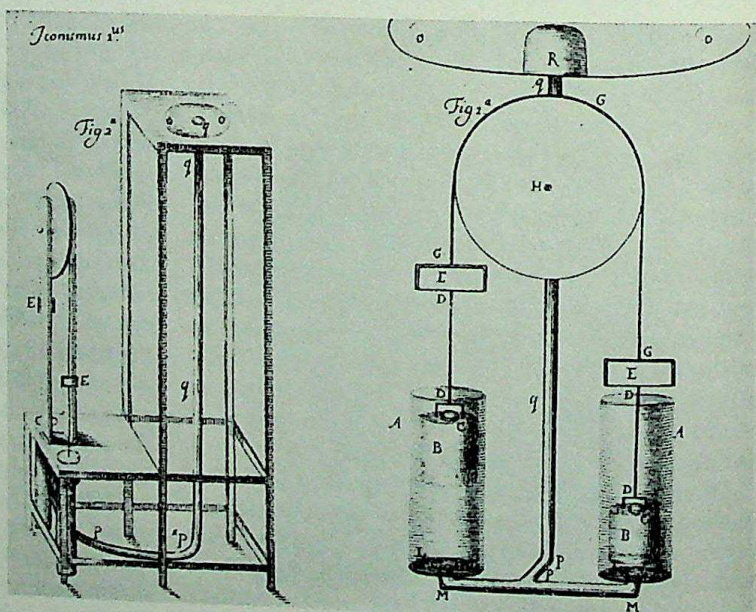


FIGURE 10 – The two-cylinder pump described by Boyle in 'A Continuation of New Experiments Physico-Mechanical', 1682.

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apparatus. Leutpold likewise favoured the Sen-guierd type.

In 1675 Papin came to England and worked as assistant to Boyle, who in 1682 described, with due acknowledgment in the Preface, the pump, shown in figure 10, which Papin had brought with him from France. The basic improvement which it embodied was the use of two cylinders, with the pistons coupled together by a cord GGG passing over a wheel, so that the pressure of the atmosphere on one did most of the work required to lift the other—a great saving of labour. The stirrups also made for ease of working.

The culmination of this kind of construction is represented by Francis Hauksbee's pump, described by him in his *Physico-Mechanical Experiments* of 1709 and illustrated in figure 11. A fine example of this pump, corresponding exactly to the illustration, is still preserved by the Royal Society as one of its treasures. Like the last Papin pump, it has two cylinders, but the pistons are worked by rack and pinion. The automatic valves were made of 'limber bladder'. The arrangement of a mercury column manometer, seen immediately under the middle of the bell-jar base, and of the bell-jar itself, is very convenient and the workmanship is excellent.

The bottoms of the cylinders were screwed to a metal base, the connection being made airtight by leather washers, which stood in water retained by the dish *dd*. The connection between the bell-jar and the plate on which it stood was likewise made airtight with wet leather. The pressure could not fall, therefore, below that of saturated water vapour at the prevailing temperature: at 15°C this pressure is about $\frac{1}{2}$ in. of mercury; at 26°C it is 1 in. Hauksbee records on one occasion a height of $29\frac{1}{2}$ in. of mercury, which would be within $\frac{1}{2}$ in. of perfect if the barometric height were normal at the time. On the occasion of a lecture which the writer gave in the character of Francis Hauksbee in 1926 the Royal Society pump was carefully overhauled and put in order, in accordance with the particulars given in Hauksbee's book and not with modern oils, for instance. It then gave regularly a vacuum within about one inch of perfect, corresponding roughly to the vapour pressure of the water.

With such a pump Hauksbee performed the first experiments on the discharge of electricity in vacuo, as described in the *Physico-Mechanical Experiments*, which, as announced on the title-page, contained 'an Account of several Surprising Phenomena touching *Light* and *Electricity*'. The far-

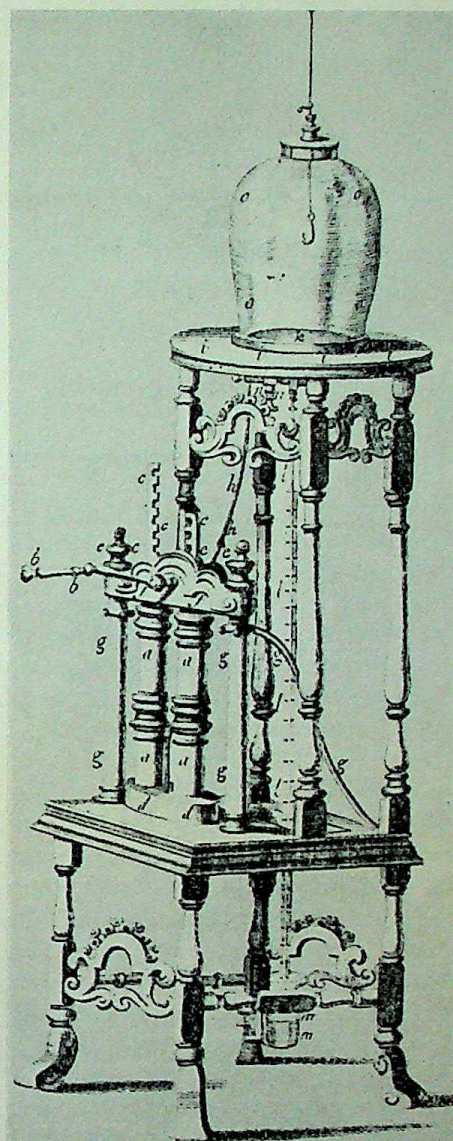


FIGURE 11 — Francis Hauksbee's pump.

reaching consequences of later experiments of this kind need no emphasis.

With Hauksbee's pump a general design was established which remained little changed in essentials until the end of the nineteenth century, when Fleuss introduced the cylinder oil pump, in which all the air was displaced from the dead space by oil, and even here the chief advance was the use of oil having a low vapour pressure. The earliest of the hand-operated pumps which periodically connected the receiver with a freshly created Torricellian vacuum did not appear until 1862, and the first rotary mercury pump was devised by Kaufmann in 1905, soon to be displaced by that of Gaede. So with the worthy Hauksbee, an experimenter of rare gifts, we close the story.

Recent developments in electronic computers

J. M. M. PINKERTON

Electronic computers are now being increasingly used not only in scientific research but in industry and commerce, and much progress has been made in the design and operation of computing machines since this subject was reviewed in *ENDEAVOUR* eight years ago. This recent progress, and future prospects, are here discussed. An important factor preventing the even more extensive application of computers is a shortage of suitably trained operators.

INTRODUCTION

In the registers of mechanical calculators, numbers are represented by shaft positions and transmitted by gearing the shafts together. In electronic computers numbers are most often represented by electrical pulses or by the magnetic state of a small area of magnetic material, and are transmitted between registers as very short electrical pulses on wires. Thus in respect of the physical representation of such abstract concepts as numbers and instruction codes, there is no essential difference between mechanical and electronic calculators. But because of their much greater speed of operation, and the facility with which electronic circuits can be interconnected and diversified, computers of an order of elaboration altogether different from that feasible with mechanical devices alone have become a practical reality.

In electronic computers numbers may be represented in either the binary or the decimal form: a binary number consists of a series of 0's and 1's representing the presence or absence of successive powers of 2. Most mathematical computers have worked in this system on account of the ease with which it can be physically represented, e.g. by two alternative directions of magnetization in a ring of magnetic oxide [1]. Some computers intended for business calculations have used the decimal system, often by employing the binary representation for each individual decimal digit [2].

A high-speed computer must hold in its store or memory not only the numbers involved in the calculation, but also full instructions governing the course of the calculation to be performed. If this were not so, its extreme speed of operation could not be utilized, since no human operator could give a thousand or more instructions per second. In all modern machines, therefore, instructions (in suitable numerical code) are held in

the same store as the numbers. This permits more flexible use of the machine, since the portions of the store assigned respectively to numbers and instructions can be varied according to circumstances. Instructions, being numerical, can themselves be changed inside the machine by simple arithmetical operations. A group of instructions may be arranged to vary according to circumstances a particular instruction which is carried out many times. In this way a dozen instructions may take the place of perhaps a hundred or more.

A hand-operated desk calculator usually has no separate store; numbers are held and arithmetic is performed in the same registers, which are few in number. In the electronic machine it is impracticable to do arithmetic in all registers of the store, numbering from 500 to 2000, so a separate organ known as the arithmetic unit is included. Numbers are taken from store, added, subtracted, multiplied or divided, and afterwards returned to store, all in response to the instructions in the programme. To ensure that instructions are executed in the sequence laid down, central control circuits are provided. These vary greatly but always include a sequence register and an instruction register, a decoding circuit for recognizing the nature of the instruction currently being carried out, and signalling circuits to co-ordinate the activity of all other parts of the machine. Most machines operate one step at a time and can execute from 100 to 10 000 or more steps per second [3].

When new data or instructions are to be presented to the machine, a record must first be made by hand on punched tape, or on cards, or on magnetic tape, to be 'read' automatically by the machine. Reading occurs in response to instructions, as does also printing or punching of results. Results, whether to be read visually or to be held for later use by the computer, must be recorded

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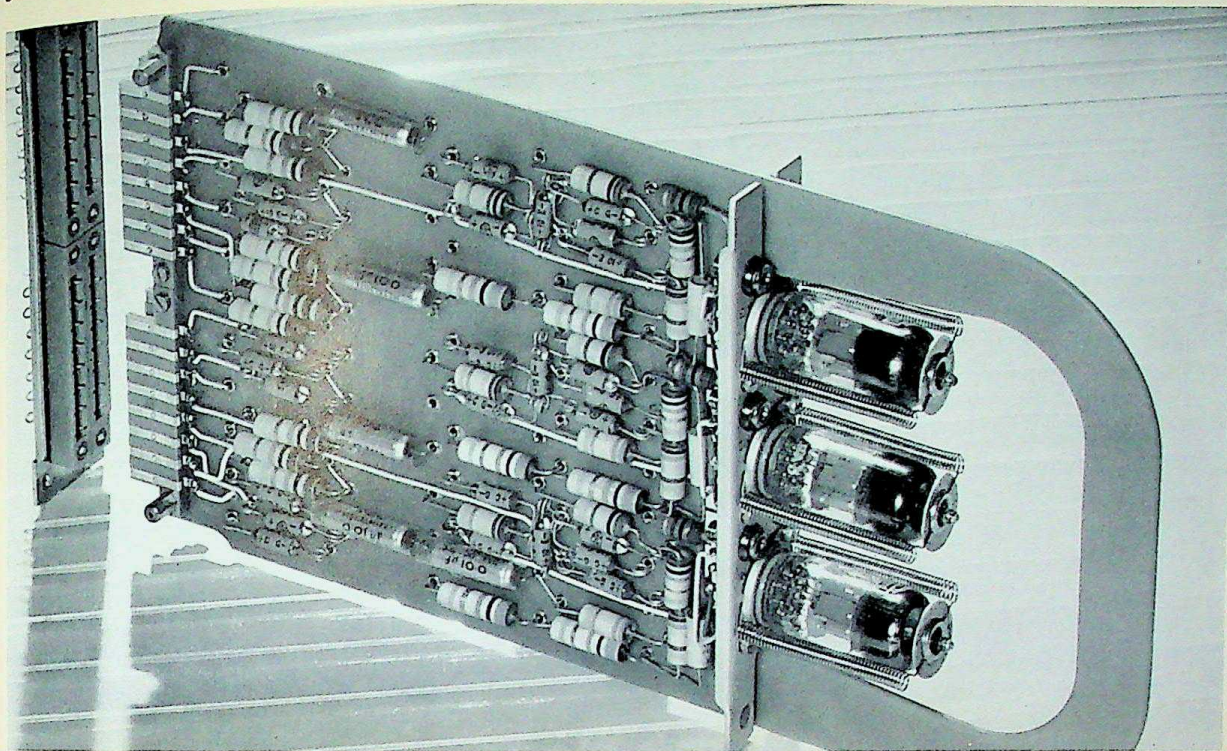


FIGURE 1 - A circuit package carrying three valves and numerous components, including many germanium crystal diodes. The package plugs into the socket on the left. (Reproduced by courtesy of Ferranti Ltd.)

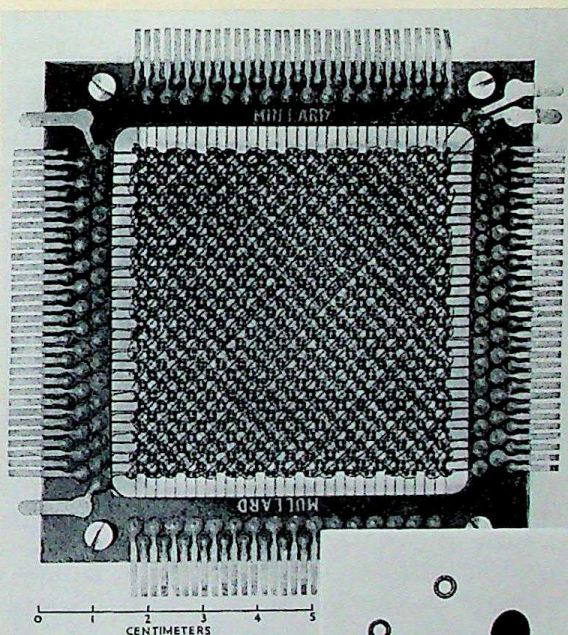
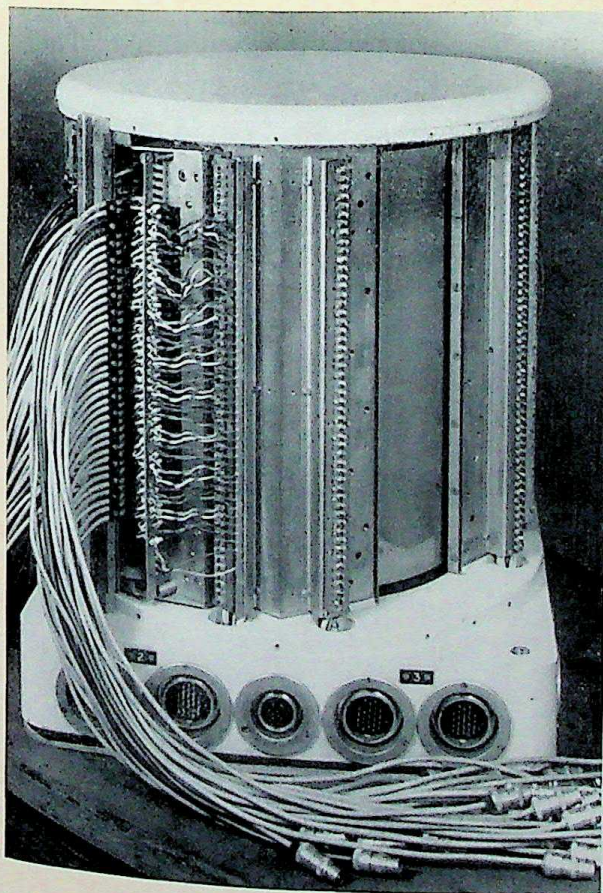


FIGURE 3 - A 32×32 'core' matrix with (inset) enlarged view of the magnetic cores compared with a match head. (Reproduced by courtesy of Mullard Ltd.)

FIGURE 2 (left) - A magnetic drum. Part of the magnetic surface of the drum is seen on the right and some of the reading and writing 'heads', with leads attached, on the left. (Reproduced by courtesy of Ferranti Ltd.)

by mechanical means under direct control of the computer. Teleprinters, automatic typewriters, punched-card punches and tabulators, and special high-speed paper tape punches are commonly employed. Magnetic tape recording machines are also used [15]; in this case the numbers on the tape can either be fed back to the computer or printed by an automatic printer dissociated from the computer.

Since both reading and writing instructions involve mechanical operations, they tend to take far longer than calculating instructions. In mathematical machines this is not objectionable, but in business machines far more data and results are involved and special steps are taken to avoid loss of time [7].

HISTORICAL

Some eight years ago D. R. Hartree [8] summarized in ENDEAVOUR contemporary computer developments and was able to mention most of the important projects then in hand. Because of the rapid advances made since then, this is now quite impossible within such a compass. Engineering progress has been especially great, methods of applying machines to mathematical problems have advanced, and machines have been applied commercially to non-mathematical tasks in accountancy and in industrial control [31]. Many machines have been in regular use for six years or more.

In the United Kingdom the most significant scientific developments have occurred in the universities of Manchester [4] and Cambridge [5, 31] and at the National Physical Laboratory at Teddington [6]. At Manchester several computers were built by F. C. Williams and his co-workers at the University, and these have given rise to a series of commercially made examples. At Cambridge emphasis has been on machine use; EDSAC I has been in use since 1949, and a second machine, EDSAC II, is now nearing completion.

In the United States there has been both scientific and commercial development on a prodigious scale. Important research projects on computers have been completed by the Bureau of Standards both in Washington and in Los Angeles [15], at the Massachusetts Institute of Technology [18], and in many other centres. The large accounting machine companies, notably I.B.M. [17] and Remington Rand [2], have been foremost in developing machines for sale or hire. Quite large and complex computers are being constructed by assembly-line methods. A high proportion of the engineering inventions in the

field have come from the United States. In Europe the principal developments other than in Britain have been in Sweden and France.

ENGINEERING DEVELOPMENTS

The enormous effort that has gone into this work in the last eight years has been aimed at increasing the speed of operation and the reliability, improving maintenance, and facilitating and cheapening production. The essential features of a machine, however, remain as described by Hartree [8].

The overall speed of a machine is governed principally by the time taken to obtain an item of information from the store. The shorter this time the more expensive does the store become; therefore, to ensure optimum efficiency, machines with 'fast' stores are usually provided with fast arithmetic units, and, if they are to be used for business purposes, with fast input and output organs as well.

The fastest machines operate at 10 000 or more steps per second and now generally use a store based on the magnetic core [1] illustrated in figure 3. Every binary digit stored requires one core to represent its value 0 or 1. The cores are arranged in matrices threaded by wires in the x and y directions; switching circuits are so designed that only if current is passed simultaneously on X and Y wires through a core may its state of magnetization be reversed and a signal be induced in the read-out wire (figure 4). Magnetization of the cores holding 1's is reversed on reading but cores holding 0's are not affected, so that the selected information is cleared on reading and means for regenerating it must be provided.

Medium-speed machines operating at from 700 to 2000 steps per second have used the ultrasonic

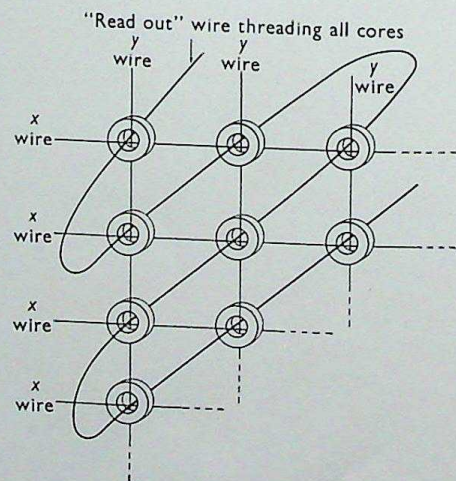


FIGURE 4 - Construction of a magnetic core matrix.

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mercury delay line, as for example EDSAC I, or the Williams tube store, as in the Manchester University machine. Another type of delay line [9], using the magnetostrictive effect, is becoming popular, and one machine, NICHOLAS, has used it for its main store [10]. In this an acoustic pulse about two or three microseconds long is transmitted down a nickel wire or tape by passing a current through a small coil near one end. At the other end the reverse magnetostrictive effect induces a small e.m.f. in a similar coil.

In slower machines, particularly in those used for some business purposes, a magnetic drum [19] is now widely used as a main store (figure 2). In the latest designs it is used as a 'backing' store in conjunction with a small fast store employing cores or delay lines. A whole block of orders is transferred from the drum to the fast store, and replaced by another after all orders of the block have been executed. Economy of storage equipment is thus combined with medium speed of operation.

Arithmetic facilities have been extended, not so much by making the machine able to do more than add, subtract, multiply, divide, and shift, as by increasing the flexibility and convenience with which it does these operations. Many machines now perform so-called 'floating-point' arithmetic. In this a number n is represented in two parts, a and b , where $n = a \times 10^b$ (or $n = a \times 2^b$ in the binary system, in which most machines work). After each arithmetical step the part a is automatically adjusted by shifting circuits in the machine to lie between $+1$ and -1 . The part b is calculated to correspond, and could range from perhaps $+99$ to -99 ; numbers held in the machine would then lie between 10^{99} and 10^{-99} . On such a system the velocity of light ($299\,793\text{ km/sec}$) would be automatically converted to 0.299793×10^6 , i.e. $a = 0.299793$ and $b = +6$. This system allows extended calculations without loss of accuracy, even when the position of the decimal point cannot be known in advance.

The input and output systems by which the machine communicates as it were with the outside world have undergone extensive development. Not only have specially rapid readers [20] and printers been developed, but the circuits connecting them to the computer have been much refined. Multiple channels for data and results have been used, particularly in machines designed for business purposes [7]. Punched tape, magnetic tape and punched cards are the most popular media for data and results; many machines have printers directly connected to them in addition.

The mechanical construction of computers has been closely studied; the tendency is to make the electronic circuits in the form of plug-in packages [16]. Originally this was mainly to facilitate maintenance, but it is now seen to make designing less laborious and production easier (figure 1).

In mass-production of any engineering article, methods of standardization to facilitate manufacture are well known. After the parts have been correctly assembled the whole must be given a thorough functional test. A computer could test itself by means of test programmes very thoroughly in a few hours, provided that there were no defects in any of the several hundred units or packages of which it is composed. In practice, however, faults do arise, and since they have to be traced in the complete machine one at a time, the final assembly tests may well take several weeks.

OPERATING TECHNIQUE

It is now recognized that the most important, as well as the most difficult, question is whether a particular computation can be tackled by a computer or not, and if so how it is to be organized. Once this has been decided in complete detail, the stages are usually scheduled on a flow diagram, and programme encoding follows. The first part of this process [13] demands full mathematical insight into the problem; the second part, though laborious and exacting, can be entrusted to trained persons without advanced mathematical knowledge. As written, programmes are seldom free from flaws, and part of the operating time of all machines is devoted to programme trials [21]. Clearly the ratio of preparation time to computing time may be very large, often more than $100:1$. Thus a problem of the type which has only to be solved once may not be economically tackled by a computer.

In both scientific and business calculations it is vitally important to be able to detect wrong results, though this is not so difficult as it seems. Experience shows that often, though not invariably, a machine produces nonsense or stops when it goes wrong. Mathematical checks are usually put into a programme so that if the data have been correctly recorded and fed into the machine, calculating errors are unlikely to pass undetected. In clerical work the usual accounting procedures can be used to give an absolute check of accuracy of working [11]. Published figures show that most machines achieve about 90–95 per cent reliability. However, the productive efficiency may be appreciably less because time is lost by data and

operating errors as well as by repeating work after breakdowns.

Methods of maintenance are constantly improving; preventive methods of marginal testing, by which gradual deterioration of valves or components is detected before it causes computing errors, are very effective and are now generally used [14]. Finding the faults which occur because of sudden or intermittent failure of some part, commonly a valve, calls for an analytical mind combined with detailed knowledge of the functioning of the machine. Shortage of trained engineers of the necessary quality will probably be the main limitation on the number of machines brought into use in the next few years. Future engineering developments will have to take this into account.

PROGRAMMING

Programming is the art of framing a problem suitably for an automatic calculation and then encoding it for the machine as a series of simple arithmetical steps. The greater art lies in the first stage of this process. This requires the job to be broken into separate stages, each stage corresponding to a separate section in the programme of instructions, e.g. to evaluate $\sin x$ or e^x for a given x . Standard sequences of instructions, known as 'sub-routines', may often be used for such stages, linked together by suitable specially written sequences. Techniques have been worked out, notably by M. V. Wilkes, D. J. Wheeler, and S. Gill [22], on the EDSAC for simplifying the writing of programmes by enabling the stages to be encoded independently, that is self-consistent only within themselves. 'Interpretative sub-routines' then cause the computer, when taking in the separate stages, to modify them as required into a co-ordinated whole. This process can be taken very far indeed, virtually endowing the machine with a new set of arithmetic capabilities, each built up, of course, from a series of simpler steps, but called into play by one 'instruction' which when 'interpreted' causes the machine to go into the required sub-routine. Development in this direction seems limited only by the ingenuity of the programmer.

Programmes could not be written unless the machine could be endowed with a limited power of choice between two paths in a programme. All computers therefore possess special conditional instructions which cause a jump in the orderly progress through the programme if, but only if, some arithmetic criterion is satisfied. This may

be the sign of the number in the accumulator register. Thus the machine can be set to repeat a sequence of instructions evaluating the successive terms of a series until no further terms are significant. At this point the machine breaks out of that sequence, sums the significant terms, and proceeds with the next part of the task.

Most machines now have special registers to permit instructions to be modified automatically and to facilitate counting the number of times a sub-routine is carried out. This feature allows, for example, the sum of n numbers to be obtained without having to use valuable storage space to hold n 'add' instructions. It was first used in the Manchester University machine [4]. Besides the purely computing routines in a programme, other routines are required for programme input, data input, and output of results. The latter particularly are often quite complex, as the printer must be instructed to set out the results on the paper: for example, an output routine has been devised to make the machine plot directly a Patterson projection in X-ray crystallography [23].

APPLICATIONS OF COMPUTERS

Computers have been used to solve a great range of scientific and technical problems [24, 25], to a limited extent to test mathematical theorems in the theory of numbers [12], and to do some of the routine calculations of commerce. The list of applications is so long that only a few can be mentioned here.

The EDSAC has been successfully used by J. C. Kendrew and J. M. Bennett [23] for computing both two- and three-dimensional Fourier syntheses from X-ray crystallographic data, and by I. W. Cochran and A. S. Douglas [26] to obtain the sign of the Fourier coefficients. Numerical solutions have been found to partial differential equations [25], and mathematical tables of functions prepared [13]. Optical problems in tracing rays through compound lenses have been solved [27]. Experiments have been made to determine whether a computer can be used in weather forecasting. Trial forecasting charts have been evaluated on a computer by F. H. Bushby and M. K. Hinds [28], using the Sawyer-Bushby model of the atmosphere. Results for 12- and 24-hour periods were encouraging, although difficulties arose in dealing with conditions at the boundaries of the area, which covered the United Kingdom and the North Atlantic as far as the seaboard of the United States.

Many problems have been solved correctly that

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could not have been tackled by hand methods of computation not only because of the labour involved, but because of the chance of a mistake vitiating the entire calculation. As an example may be cited the computing of the co-ordinates of the five outer planets at 40-day intervals for the period 1653 to 2060. This was done jointly by the U.S. Naval Observatory in Washington, the Yale University Observatory and the I.B.M. Corporation using the Selective Sequence Calculator [29]. The mutual attractions of the five planets and the Sun were expressed by a set of simultaneous non-linear differential equations of the 30th order, which were solved to an accuracy of 14 decimals. The resulting coordinates correctly represent the observations over a period of 150 years within the probable error and are more accurate than those obtained from Hill's Tables.

A computer has recently been used to control a milling machine by absorbing data from an engineering drawing and punching out instructions into paper tape. The tape is 'read' and controls the movements of the workpiece in three dimensions by very accurate servo mechanisms. The same tape can be used many times, and one computer can easily provide control tapes for many machine tools [30].

Commercial clerical work, provided that it is of a repetitive and routine character, can be

transferred to a computer so that all the steps can be specified exactly in advance. It is, however, unnecessary that every stage should be performed in the same way each time the routine is carried out. In payroll calculation, for example, one man may have worked normally, another have been sick, a third on holiday, and so on; all these variations are dealt with by appropriate sections of the programme, and instructions that do not apply are short-circuited. It is the ability to deal with the widely varying circumstances of everyday business that makes a computer so valuable in an office. Whether it is economical to do office work by machine depends on whether there is a sufficient volume of routine work to justify the initial cost of the machine and the trouble and expense of re-planning the work for the computer. A large computer, LEO, a development of the Cambridge EDSAC, with multi-channel input and output facilities, has been in regular daily use for over two years in Britain in the offices of a large catering firm [7, 11].

The rate of progress is being limited by the scarcity of engineers, mathematicians, and accountants with experience of using computers. In an effort to overcome the shortage, the tendency will be towards standardization of the computer as a whole and more particularly of its parts, the programming techniques and operating methods.

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Polar and tropical aurorae

JAMES PATON

It is not generally known that aurora, typically a phenomenon of high latitudes, occasionally occurs also in low latitudes, even near the equator. Further knowledge of these low-latitude displays is urgently needed to amplify our understanding of auroral processes, and observation of them is an important part of the programme of the forthcoming International Geophysical Year. ENDEAVOUR welcomes the opportunity of lending its support to an appeal, contained in this general review of auroral phenomena, for reliable reports of their occurrence in low latitudes during the Geophysical Year commencing on 1st July 1957.

The upper atmosphere over the whole earth continuously emits a feeble light, but even on a moonless night this airglow is usually too weak to be visible to the eye. There is, however, an almost continuous emission of much stronger light which is easily visible during the dark hours in two zones girdling the earth at about 23° from the north and south magnetic poles respectively. This is aurora: aurora borealis in the northern hemisphere and aurora australis in the southern hemisphere. During the period of sunspot maximum, aurora may extend far from its normal zones for periods of many hours, and may become visible over a large area of the globe stretching from the poles sometimes almost to the equator. When the luminosity increases beyond the threshold of colour perception, observers are treated to a weirdly pulsating display of variegated colour in the sky, of a magnificence that beggars description. So fantastic may be the appearance of a great aurora that it has been known to excite apprehension, even panic, among those unfamiliar with it.

The light of aurora is produced quite differently from that of the airglow. The latter derives its energy from the store accumulated during the day, when solar ultra-violet light ionizes and dissociates the atmospheric gases at great heights. The resultant chemical reactions among the ionized and dissociated products release the stored energy in the form of radiation (the night airglow), which is therefore emitted over the whole globe. Aurora, on the other hand, is caused by the entry into the high atmosphere of a stream of charged particles, ions and electrons, originating in the sun. Electromagnetic deflection by the earth's magnetic field causes the stream of particles to precipitate over limited regions of the earth, the precise zone of precipitation depending on the speed, constitution, and direction of incidence of the stream. The auroral light is emitted

mainly by the bombarded atmospheric gases, and sometimes also by protons in the incident stream which have captured an electron.

Since aurora is visible on every clear night in the northern and southern auroral zones, it appears that a stream of corpuscles of solar origin continuously approaches the earth with a speed and density such as to limit precipitation to these zones. Besides causing aurora, the solar corpuscular stream increases the ionization during its passage through the upper atmosphere and produces changes in the ionosphere. These in turn produce changes in the upper atmospheric current systems that reveal their presence by perturbations in the earth's magnetic field. It is not surprising, therefore, that the intensity of geomagnetic disturbance is normally greatest near geomagnetic latitude 67° , i.e. in the auroral zones.

A great aurora that is seen widely over the earth generally follows the occurrence of an intense flare or eruption in the central portion of the sun's disk. This observation provided, in fact, the first convincing evidence for the solar origin of aurora. The sequence of terrestrial events that accompany and follow the flare is as follows. Almost simultaneously with the flare occur a short-wave radio fade-out and magnetic crochet, i.e. a small but sudden disturbance in the earth's field. These effects, being confined to the sunlit side of the earth, are undoubtedly caused by the intense ionization in the upper atmosphere produced by a burst of ultra-violet light from the flare; this burst takes a mere eight minutes to reach the earth. It is not until about 24 hours later, however, that there occur a great and widespread aurora and a magnetic disturbance so severe as to earn the name 'magnetic storm'. The delay in the occurrence of these later phenomena is most readily explained by the assumption that they are caused when a stream of material particles,



FIGURE 1 - *Rayed band developing into curtain.*



FIGURE 2 - *Rays seen through glow on horizon.*



FIGURE 3 - *A corona.*

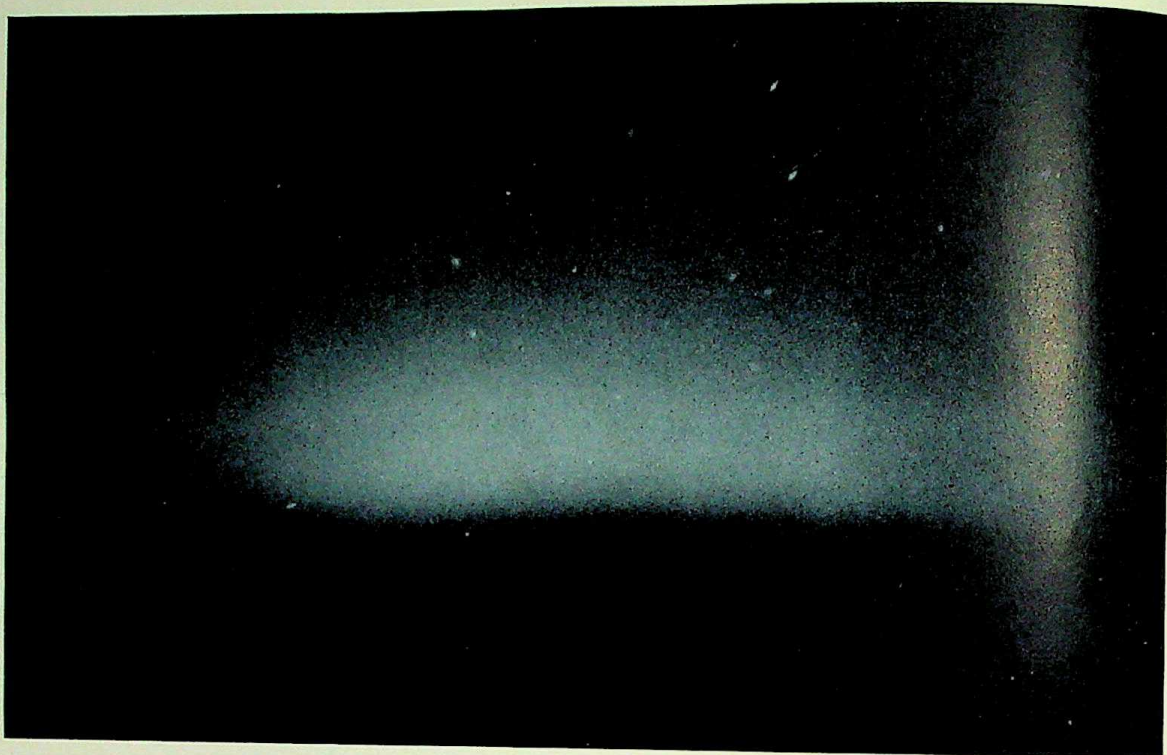


FIGURE 4 - *The top of a quiet, diffuse arc.*



FIGURE 5 - *The diffuse arc shown in figure 4 bursts into rays.*

ejected from the sun at the time of the flare, enters the upper atmosphere after making the journey from sun to earth in 24 hours; on this reasoning the speed of the particles must be of the order of 1500 km per second. Since flares are closely associated with sunspots, auroral occurrences in regions farther from the auroral zones than, say, the north of England (geomagnetic latitude 57°) follow the eleven-year sunspot cycle.

During the years of sunspot minimum, however, aurora continues to be seen quite frequently even as far from the auroral zones as the north of England. These aurorae recur at 27-day intervals, and are thought to be caused by a particle stream which, for a long period, continues to issue, rather like a jet of water from a hose, from a restricted area of the sun: this has been called an M-region by J. Bartels. The period of rotation of the sun, as observed from the earth, being about 27 days, such a stream would sweep across the earth with this periodicity, causing these recurrent aurorae to become visible in regions within about 10° of the auroral zones.

The behaviour in the earth's magnetic field of a solar stream consisting of ions and electrons, but with no overall charge (see page 46), approaching and sweeping past the earth, has been examined theoretically by S. Chapman and V. C. A. Ferraro [1] and by H. Alfvén [2]. The problem is of the utmost difficulty and little progress has been made towards a satisfactory theory of aurora, though Chapman and Ferraro may have provided an acceptable explanation of the initial stages of a magnetic storm. While the emission of auroral light is generally thought to result mainly from the excitation and ionization of atmospheric atoms and molecules directly by the primary particles in the solar stream, or by secondary electrons ejected during their passage through the atmosphere, Alfvén regards aurora as a gaseous discharge which may carry current between space charges, associated with the stream at a great distance from the earth, and the ionosphere.

Aurora is on the average visible on perhaps ten nights of the year in the south of England, northern France and Germany, and the northern parts of the United States. Usually it appears in these places merely as a glow along the northern horizon, closely resembling dawn (figure 2). Indeed, it acquired its name aurora borealis, the northern dawn, from its usual appearance to observers in these populous regions. It belies this name during a great display, when the glow ascends in the sky to form a quiet and regular arc (figure 4); later the arc suddenly brightens and

disintegrates into a series of irregular rayed bands (figure 5), whose folds cause them to appear like huge curtains waving in the sky (figure 1). When streamers or rays extend overhead from the draperies into the southern sky, they appear by perspective to converge to the point in the sky to which the south pole of a magnetic dip needle is directed. The streamers are therefore parallel, and coincide with the lines of force of the earth's field. This most striking of auroral forms is called a corona (figure 3). As the display reaches its climax and begins to recede northwards, there is usually much flaming; waves of light surge upwards from the horizon to the zenith.

Investigation of the auroral spectrum is important not only for the information it may yield concerning the origin of aurora but because it provides a means of determining the composition and properties of the atmosphere at the levels where auroral light is emitted. The experimental difficulties are formidable, for the intrinsic luminosity is low and the brightest auroral forms are usually in rapid movement. Further, the long time-interval between successive collisions of atoms and molecules in the upper atmosphere leads to emissions associated with transitions that violate the selection rules, i.e. to so-called forbidden emissions, which cannot easily be reproduced in the laboratory. The identification of the origin of spectral lines is therefore often difficult, and the lines themselves may sometimes be obscured by overlapping band-systems. Lines of neutral and ionized atomic oxygen and nitrogen and band systems of neutral and ionized molecular oxygen and nitrogen have been identified. The processes that may be responsible for the various emissions are numerous and have recently been examined by D. R. Bates [3].

The recent use of spectrographs of great resolving and light-gathering power, which provide measurable spectra with short exposure times, has made possible the examination of the spectral characteristics of short-lived auroral features. In this way emissions of lines by elements present in the incident solar stream that causes aurora have been identified. The Balmer lines of hydrogen were first identified by L. Vegard and confirmed by C. W. Gartlein. The measurement by A. B. Meinel [4] of the Doppler displacement of the $H\alpha$ line in the spectrum of an arc near the zenith showed that protons in the incident solar stream possessed velocities of the order of 3300 km per second. Since their light emission can occur only when the proton has been slowed down sufficiently

to capture an electron, the speed with which the protons enter the upper atmosphere must be considerably greater than that determined from the Doppler shift. The $H\alpha$ emission was observed to cease when the quiet arc disintegrated into rays, so apparently protons play no part in the formation of rays. There is some spectral evidence that sodium also is present in the solar stream.

We owe much of our knowledge of general auroral characteristics to the great work of Carl Störmer and his colleagues in Norway. Störmer was attracted to this study in the early years of the century on seeing a spectacular experiment performed by his colleague Kristian Birkeland. In an attempt to reproduce aurora in the laboratory Birkeland exposed a magnetized sphere, simulating the earth, to a stream of cathode rays in a large discharge vessel. The precipitations of the rays on the sphere were made visible by the fluorescence of a coating material and, by suitable adjustments, could be made to take the form of well defined spirals round each pole. This apparently close experimental reproduction of aurora inspired Störmer [5] to embark on the difficult and laborious task of computing numerically the trajectories of an electron moving in the field of a dipole, and he has thus provided explanations of some of the forms assumed by aurora. The objection to the hypothesis of a stream of particles all carrying charge of the same sign is that mutual electrostatic repulsion would disperse it long before it reached the earth. It is for this reason that the more recent theories are based on a solar stream consisting of ions and electrons. An extension of Störmer's classic work has, however, an important application in cosmic ray theory.

When Störmer began his theoretical work, accurate information concerning the height and disposition in space of the various auroral forms was lacking. He therefore devised an ingenious photographic method [5] of making these measurements, which were necessary for the verification of the theory. Using specially designed cameras, simultaneous exposures are made on the same feature of an aurora at two or more stations separated by distances of from thirty to a few hundreds of kilometres. By measuring the parallax displacement, with reference to the star background, of corresponding auroral points on a pair of pictures, height and position are determined. By this method Störmer found that the brightest auroral features are usually situated at heights near to 100 km, though they may occasionally come as low as 70 km. He found that near

dawn or sunset, rays may extend to enormous heights—to as high as 1000 km.

The photographic study of aurora is limited to the periods during the dark hours when the sky is clear. But there can be little doubt that aurora occurs by day as well as by night, for the magnetic storm which accompanies aurora by night continues during the day. Radio-echo methods now being developed may afford a means of making a continuous study of the phenomenon uninterrupted by cloud, moonlight, twilight, or daylight. During the Polar Year of 1932–33, E. V. Appleton and his colleagues [6] showed that aurora is accompanied by an increase in ionization below the E-layer of such intensity that at these times investigation of ionospheric conditions by conventional probing methods using frequencies in the range 1–20 Mc/s is impossible, so great is the attenuation produced. It was later found, however, that echoes could be obtained during auroral activity by using higher frequencies. In 1947 A. C. B. Lovell and his colleagues [7] at the Jodrell Bank Experimental Station, using a frequency of 46 Mc/s, recorded reflections that appeared to come from a luminescent cloud at the end of a ray. Similar observations have since been made in Scandinavia and North America. The interpretation of the origin of the echoes is still uncertain. Some experimenters [8], finding no correspondence between the range of the echoes and the position of the auroral forms, propose that they are not true echoes from aurora but simply back-scatter from the earth's surface, the sounding pulse of radiation travelling outwards by reflection at the abnormal E-layer and backwards by a similar path. But most observations suggest that the echoes are produced either by scattering from columns of ionization associated with auroral rays or by total reflection at dense isotropic clouds of ionization [9]. Thus investigation by radio-echo methods has so far yielded only limited information; indeed, just at the time of night when aurora is most frequently observed visually (about 21 hrs G.M.T. in Britain) the rate of occurrence of radio echoes is at a minimum.

AURORA IN THE GEOPHYSICAL YEAR

On 1st July 1957 geophysicists all over the globe will begin observations on an internationally agreed plan for a study of the earth and its atmosphere [10]. Included in this are elaborate plans for a world-wide study of aurora, using all the techniques available. This work will naturally be concentrated in regions in and near the auroral

zones, but since the International Geophysical Year (I.G.Y.) has purposely been chosen to coincide with the period of maximum sunspot activity, during this period aurora is certain to be seen at times in low latitudes, perhaps even close to the equator. Though there are substantiated accounts of observations of aurora in tropical regions—it was seen, for example, in Singapore (latitude 1° N) on 25th September 1909—Professor S. Chapman, chairman of the special committee for the I.G.Y. and co-ordinator of the aurora observation programme, after searching all available records has found no adequate observations of the characteristics of a tropical aurora. He has stressed the importance of obtaining such observations during the I.G.Y., pointing out that the intensive studies undertaken in and near the auroral zones will be incomplete if details of aurorae that penetrate to low latitudes are lacking [11]. It is therefore important to arouse the interest of all observers in tropical and subtropical regions—and not merely those formally associated with the I.G.Y. programme—in the phenomenon and to make them aware of the fact that they are in a position to provide information of great value simply by using their eyes and recording accurately the form of any unusual luminosity that they may see in the night sky.

During the I.G.Y. a continuous watch will be kept on the surface of the sun at solar observatories, and warning will be issued from a World Prediction Centre when solar activity indicates that a widespread aurora is more likely than usual. The warnings will be immediately distributed among all those involved in auroral and related investigations, and also will be announced in news bulletins of radio services throughout the world. It is hoped that observers in low latitudes will then look out for aurora in the night sky and make an accurately timed record of its progress when it becomes visible. Crews of aircraft flying in tropical regions are particularly favoured from the point of view of sky observation, since cloud is less likely to interfere and they may see more distant aurorae

than the land-based observer. While in the majority of cases the watch for aurora may go unrewarded, the probability of witnessing a rare spectacle is sufficiently high to justify regular observation. Since the chance of seeing aurora is greater the nearer the observer is to the magnetic pole, successful observation of a tropical aurora is more likely, for example, in Central America than in southern India.

While it is most important that watch for tropical aurorae be kept during the I.G.Y., when there is world-wide observation of all geophysical phenomena, it is very desirable that auroral observation be continued for a year or two afterwards, because past observations have shown that solar-terrestrial effects tend to be greatest in the years following the sunspot maximum.

Assistance in searching official records, newspapers, ships' logs, diaries, and letters for accounts of past tropical aurorae would also be welcome.

The dates of the twelve greatest magnetic storms recorded at Greenwich during the period 1874–1954 are: 1882, 17th and 20th November; 1903, 31st October; 1909, 25th September; 1921, 13th May; 1938, 25th January and 16th April; 1940, 24th March; 1941, 1st March and 18th September; 1946, 28th March and 21st September. The study of documents relating to the time of their occurrence is particularly likely to be fruitful. Further particulars of the tropical aurorae of 1859 (28th August to 2nd September) and 1872 (4th February) would also be valuable.

Detailed observations of low-latitude aurorae in combination with other information amassed during the I.G.Y. may make it possible for the first time to piece together world synoptic pictures showing successive stages in the development and decay of a great aurora.

Reports of tropical aurorae and any inquiries relating to auroral observations should be sent to the writer of this article (Mr J. Paton, Department of Natural Philosophy, The University, Edinburgh, Great Britain), who is correspondent for the Aurora and Airglow Section of the British National Committee for the I.G.Y.

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The structure of insulin

F. SANGER and L. F. SMITH

The biological importance of proteins needs no emphasis, for they play a remarkable variety of roles. Some, such as collagen or keratin, are structural; others, such as actomyosin and haemoglobin, perform specific chemical functions. Others function as enzymes, selectively catalysing metabolic processes. The hormone insulin, which is concerned with the regulation of glucose metabolism and is used in the control of diabetes, is a protein of exceptional importance, and the recent elucidation of its structure is a chemical feat of the first order.

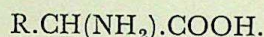
Most of the energy for the body is derived from the breakdown of glucose, and it is essential that the glucose concentration in the blood should remain relatively constant. If it becomes too low, convulsions and shock result; if it is too high, coma may occur. It is thus necessary for the body to have a means of controlling the level of glucose in the blood, and insulin is one of the main factors involved in this. It is produced by the islets of Langerhans, groups of cells situated in the pancreas. When the blood glucose level is high, these cells are stimulated, insulin is secreted into the blood and transported throughout the body, where—by some unknown process—it catalyses the removal of glucose from the blood. In diabetes, the functioning of the islets of Langerhans is impaired and they cease to secrete sufficient insulin to keep the blood glucose low enough, and this leads to the characteristic symptoms of the disease. These can be alleviated by injecting insulin, which is now prepared on a large scale from the pancreases of cattle or other animals.

Whatever the physiological function of a particular compound, it is clear that it will depend on the substance's exact chemical structure. It is therefore not surprising that much effort has been devoted to the study of proteins, since these play such a remarkable diversity of biological roles. Progress in this field has, however, been slow because of the large size and extreme complexity of protein molecules. Only recently has it been possible to write the complete chemical formula for even one protein. This protein is insulin, and the work on its structure is the subject of the present article.

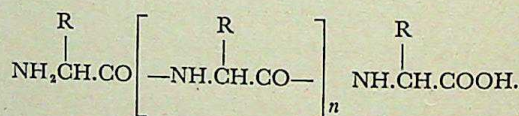
Much work has been devoted to the determination of the molecular weights of proteins. In general they have been found to be large molecules with molecular weights lying between about 5000 and several million. Insulin is one of the smallest, having a molecular weight of 5733 [1, 2].

In aqueous solution, however, it undergoes aggregation, so that the apparent particle weight is considerably greater.

The fundamental components from which proteins are built up are the amino acids, most of which have the general formula



Twenty-one of these acids, differing in the nature of the R group, occur commonly in most proteins: they are listed in Table I. Insulin contains all of them except methionine, tryptophan, and cysteine. The amino acid residues are joined together in proteins by the formation of amide or peptide bonds between the α -carboxyl group of one residue and the α -amino group of another. In this way they form long polypeptide chains of the general structure:

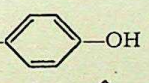
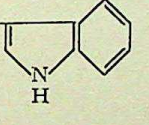


When a protein is hydrolysed with strong acid, the peptide bonds are broken and a mixture of the component amino acids is obtained: by suitable analytical procedures the number of residues of each can be determined. In this way it was possible to write an empirical formula for insulin in terms of its amino acid content (table I); the next problem was to find how the amino acid residues were arranged together in the molecule.

From the formula for a polypeptide chain given earlier we can distinguish three types of residues. Most of the amino acids are present in the form $-NH.CHR.CO-$; that is, with their amino and carboxyl groups blocked. On the left of the formula is a residue with a free α -amino group ($NH_2.CHR.CO-$). This is known as the N-terminal residue, and by making use of suitable chemical reactions it is possible to identify and

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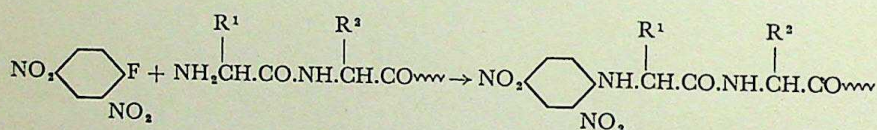
TABLE I
Common naturally occurring amino acids

Amino acid	Structure of R group	Abbreviation used for residue —NH—CH(R)—CO—	Number of residues in insulin
<i>Aliphatic</i> Glycine	—H	Gly	4
Alanine	—CH ₃	Ala	3
Valine	$\begin{array}{c} \text{CH}_3 \\ \\ \text{—CH—} \\ \\ \text{CH}_3 \end{array}$	Val	5
Leucine	$\begin{array}{c} \text{CH}_3 \\ \\ \text{—CH}_2\text{—CH—} \\ \\ \text{CH}_3 \end{array}$	Leu	6
Isoleucine	—CH(CH ₃)—CH ₂ —CH ₃	Ileu	1
Serine	—CH ₂ —OH	Ser	3
Threonine	—CH(OH)—CH ₃	Thr	1
<i>Aromatic</i> Phenylalanine	—CH ₂ — 	Phe	3
Tyrosine	—CH ₂ — 	Tyr	4
Tryptophan	—CH ₂ — 	Try	0
<i>Acidic</i> Aspartic acid	—CH ₂ —COOH	Asp	0
Glutamic acid	—CH ₂ —CH ₂ —COOH	Glu	4
<i>Acid amides</i> Asparagine	—CH ₂ —CONH ₂	AspNH ₂	3
Glutamine	—CH ₂ —CH ₂ —CONH ₂	GluNH ₂	3
<i>Basic</i> Lysine	—CH ₂ —CH ₂ —CH ₂ —CH ₂ —NH ₂	Lys	1
Arginine	$\begin{array}{c} \text{NH} \\ \\ \text{—CH}_2\text{—CH}_2\text{—CH}_2\text{—NH—C—NH}_2 \end{array}$	Arg	1
Histidine	$\begin{array}{c} \text{N} \\ \\ \text{—CH}_2\text{—C—} \\ \quad \\ \text{HC} \quad \text{CH} \\ \diagup \quad \diagdown \\ \text{N} \\ \\ \text{H} \end{array}$	His	2
<i>S-containing</i> Cysteine	—CH ₂ —SH	CySH	0
Cystine	—CH ₂ —S—S—CH ₂ —	CyS—CyS	3
Methionine	—CH ₂ —CH ₂ —S—CH ₃	Met	0
<i>Cyclized</i> Proline	$\begin{array}{c} \text{H}_2\text{C—CH}_2^* \\ \quad \\ \text{H}_2\text{C} \quad \text{CH—COOH} \\ \diagup \quad \diagdown \\ \text{N} \\ \\ \text{H} \end{array}$	Pro	1

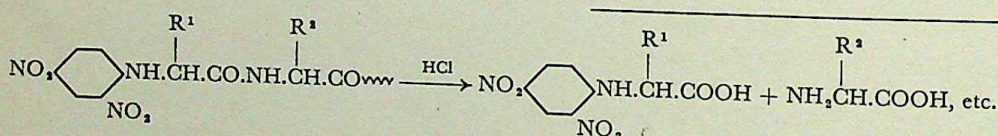
* Complete structure of the amino acid.

estimate such residues. At the other end of the chain is the C-terminal residue, which has a free α -carboxyl group. The study of terminal residues has assumed considerable importance in protein chemistry, since not only is it possible to locate the position of certain residues in the chain in this way, but it also gives some information about the general overall structure of the protein. It can be used for the characterization of a protein and is a useful test of purity [3-5]. Since each open polypeptide chain has one N-terminal and one C-terminal residue, an estimation of these can be used to determine the number of chains present, provided there are no cyclic or branched chains.

As an initial attack on the insulin molecule a general method was developed for the identification and estimation of N-terminal residues [6]. 1-fluoro-2,4-dinitrobenzene (FDNB) reacts with amino groups of peptides and proteins to give dinitrophenyl (DNP) compounds:

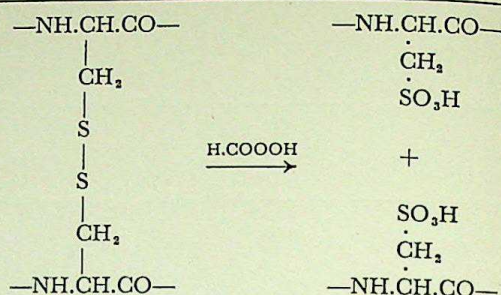


On acid hydrolysis this new bond is in general more stable than peptide bonds, so that one obtains amino acids and the DNP derivative of the N-terminal residue:



The yellow DNP-amino acids can be isolated and identified by chromatography on silica gel columns or on filter paper. By this method both glycine and phenylalanine were found to occupy N-terminal positions in insulin, suggesting that there were at least two polypeptide chains in the molecule, one having N-terminal glycine and the other an N-terminal phenylalanine residue.

Insulin contains three residues of cystine, and as can be seen from its structure (figure 1), this amino acid is capable of linking two polypeptide chains together through a disulphide bond. To break these disulphide cross-links insulin was oxidized with performic acid, which converts one residue of cystine to two residues of cysteic acid (abbreviated CySO_3H)



After this treatment it was possible to isolate two fractions: one acidic, having only N-terminal glycine (fraction A), the other basic, having only N-terminal phenylalanine (fraction B) [7]. Further evidence showed that each fraction was homogeneous and that the A chain had 21 amino acid residues, of which four were cysteic acid, and the B chain 30 residues, of which two were cysteic acid. In this way the insulin molecule had been split into its two constituent polypeptide chains; this simplified the next problem, which was to determine the complete sequence of amino acids in the two chains.

The basis of the method used can be illustrated in the following manner. If we have a dipeptide the amino acid composition may be determined after complete hydrolysis of a sample. Suppose it

gives two amino acids, A and B. Another sample is treated with FDNB and the N-terminal amino acid determined. If this is A, then the structure of the dipeptide must be A.B (by convention the amino acid having the free amino group is written on the left). This reasoning can be extended to give the structure of larger peptides by first partially hydrolysing them to give a series of dipeptides the structures of which can be proved; the structure of the large peptide can be deduced from these. Thus a peptide A.B.C.D on partial hydrolysis might produce dipeptides A.B, B.C, and C.D, from which a unique sequence for the tetrapeptide could be deduced. If a particular residue occurs more than once in a peptide the complete structure cannot be worked out from

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dipeptides and it is necessary to obtain some larger peptides.

This was basically the method applied to the elucidation of the amino acid sequence of the A and B chains of insulin. The difficulty with large polypeptides of this nature was the technical one of isolating the peptides from a partial hydrolysate, for if the procedure outlined above is to be valid the peptides must be pure. Thus from a linear polypeptide of 30 residues such as fraction B, one could get 29 dipeptides, 28 tripeptides, 27 tetrapeptides, etc. In actual practice it is possible to reduce this number in two ways. If the polypeptide is being hydrolysed with acid, the hydrolysis is continued for a sufficient time to ensure that most of the larger peptides have been broken down and that the mixture contains only small peptides and free amino acids. Another method is to hydrolyse with proteolytic enzymes. In this way only peptide bonds adjacent to certain amino acids are broken. For instance, trypsin, a pancreatic enzyme, will hydrolyse only peptide bonds formed by the carboxyl groups of lysine or arginine. Thus a peptide Gly.Glu.Arg.Gly.Phe, which could give four dipeptides, three tripeptides, and two tetrapeptides on acid hydrolysis, would give only two peptides—Gly.Glu.Arg and Gly.Phe—after treatment with trypsin. Even with these two methods of partial hydrolysis the fractionation of the peptides produced was still a major problem, and it was only after the introduction of paper chromatography [8, 3, 9] that it was possible to attempt to fractionate such complex mixtures. This proved to be the most useful method throughout this work, especially for the small peptides produced by acid hydrolysis. With large peptides better separations were usually obtained by electrophoresis on paper [10, 11, 13]. Ion exchange and adsorption chromatography have also been used for preliminary fractionations of the mixtures.

As an example, we can show how one part of the sequence of the B chain was deduced. Aspartic

acid occurs only once in the chain, and therefore any peptide containing aspartic acid must be part of a single sequence. Two dipeptides, Val.Asp and Asp.Glu, were found in a partial acid hydrolysate giving the sequence Val.Asp.Glu. This was confirmed by the identification of a tripeptide Val.(Asp,Glu). (The inclusion of the residues in brackets in the formulae for peptides indicates that their relative order is unknown.) Another tripeptide Phe.(Asp,Val) extended the sequence to Phe.Val.Asp.Glu and a pentapeptide Phe.(Asp, Glu,His,Val) suggested that the residue following glutamic acid was histidine.

From the small peptides produced by partial acid hydrolysis many sequences were deduced, but it was not possible to determine the complete sequence of the B chain by this method; for instance, no peptide containing serine was found in which serine did not occupy the N-terminal position. This suggested that the peptide bond formed by the amino group of serine was very labile and under the conditions used was always broken, thus making it impossible to determine which amino acid preceded serine. In order to complete the sequence it was necessary to study the larger peptides produced by enzymic hydrolysis, and in this way the structures of both the A and the B chains were determined [12, 13] and are shown in figure 1. The —NH_2 groups indicate the presence of the amide residues asparagine and glutamine. On acid hydrolysis these residues break down to ammonia and aspartic or glutamic acids respectively. They remain intact, however, during enzymic hydrolysis and could be located in this way [14].

The final problem was to show which of the half cystine residues were joined together in the intact insulin molecule. For this it was necessary to isolate peptides containing cystine residues and to determine their structure. The method may be summarized as follows:

1. Partial hydrolysis of insulin under conditions in which the disulphide bonds remain intact.

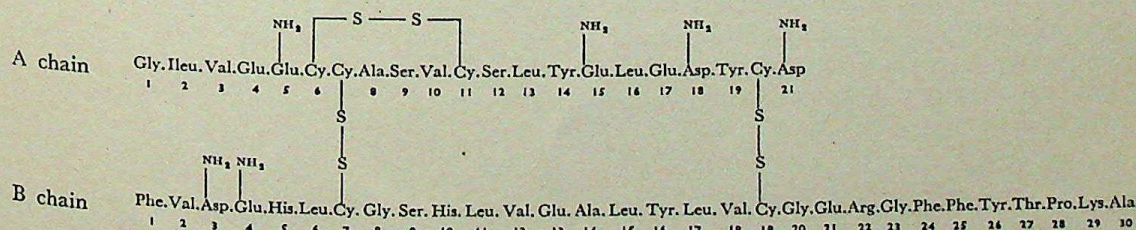


FIGURE 1—Structure of cattle insulin.

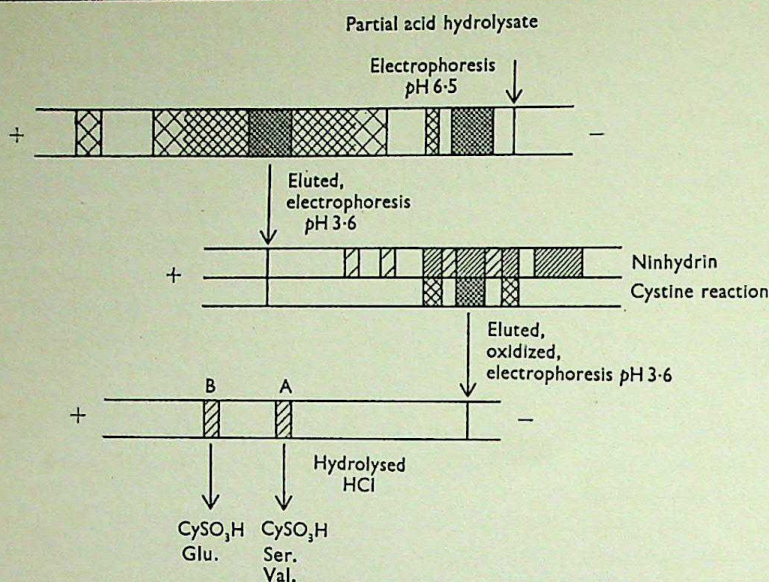
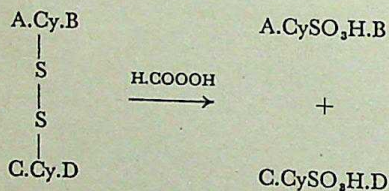


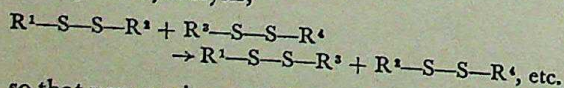
FIGURE 2 - Diagram showing the method of isolation and identification of a cystine peptide from insulin.

2. Separation of cystine peptides from one another.
3. Oxidation of cystine peptides to cysteic acid peptides, e.g.



4. Identification of the cysteic acid peptides from the amino acids produced on hydrolysis. These peptides had already been obtained from partial hydrolysates of the A and B chains and therefore their structures and positions in the chains were known. From this the structure of the original cystine peptide and the position of the disulphide bond in the insulin molecule could be inferred.

An unexpected difficulty, however, was that when the peptides were obtained from a partial acid hydrolysate no unique structure could be deduced; all half-cystine residues seemed to be linked with all the remaining half-cystine residues. This was clearly impossible and suggested that some form of rearrangement was taking place during the hydrolysis,

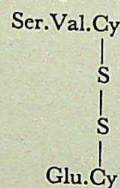


so that new cystine peptides had been formed that were not true fragments of insulin.

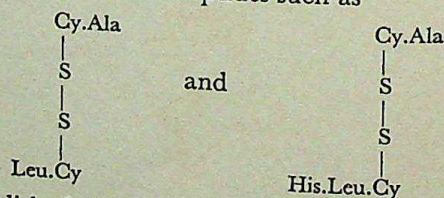
This reaction was studied in some detail [15], and it was discovered that it could be inhibited by the addition of small amounts of thiol compounds, so that conditions were eventually devised for the isolation of cystine peptides that were in fact fragments of the original insulin. The method of isolation and identification of a typical peptide which gave the position of one disulphide bond is summarized in figure 2.

The insulin was first hydrolysed with acid under the special conditions necessary to avoid rearrangement of the disulphide bonds: The peptide mixture was then fractionated by electrophoresis on paper to give a number of bands. These were,

however, not yet sufficiently resolved, and so were eluted and subjected to a second electrophoresis at a different pH. The position of the peptides was found by using the ninhydrin reagent which reacts with all peptides, and also by using a specific reagent for cystine peptides. In this way a pure cystine peptide was obtained, which was oxidized to give two cysteic acid peptides A and B. These were separated by electrophoresis and each was subjected to complete hydrolysis. From their amino acid composition they were recognized as the peptides Ser.Val.CySO₃H (positions A9-11) and Glu.CySO₃H (positions A5-6) respectively. The original cystine peptide was therefore:

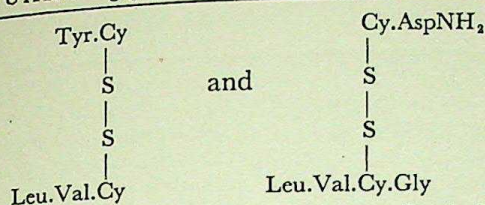


thus establishing the presence of a disulphide bridge between the half-cystine residues in positions A6 and A11. Peptides such as



established the position of the second disulphide bond joining positions A7 and B7. The peptides

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confirmed the remaining one (A20 to B19). These bonds are shown in figure 1, which gives the complete structure of cattle insulin [2, 16].

The structure shown in figure 1 is the structure of a substance which has a unique and characteristic physiological activity, and this raises the problem of the relationship between the chemistry of insulin and its activity. Is the whole of the molecule essential, or does the activity depend on an active centre composed of a limited number of amino acid residues? Studies of chemically modified insulins indicate that the latter is most probable since certain groups, such as the amino groups, may be blocked without loss of activity. The disulphide bridges probably play an important role, since breaking them causes immediate loss of activity. Of particular interest is the intrachain bridge linking positions 6 and 11 in the A chain, since a bridge of the same size is found in two other hormones, oxytocin and vasopressin, which are produced by the posterior lobe of the pituitary gland.

One approach to the problem of determining the reasons for the activity of insulin is by studying insulins from different animals. All insulins show the same activity, so that it might be concluded that any differences found would be in parts of the molecule that are not physiologically important. Sheep, pig, horse, and whale insulins have been studied [17] and were found to have amino acid compositions slightly different from those of the cattle material, but the differences are limited to the positions between the intrachain cystine residue. The various sequences are shown in table II.

TABLE II

The amino acid sequence in positions A7-10 of insulins from various species

Cattle	..	..	CySO ₃ H.Ala.Ser.Val
Pig	..	..	CySO ₃ H.Thr.Ser.Ileu
Sheep	..	..	CySO ₃ H.Ala.Gly.Val
Horse	..	..	CySO ₃ H.Thr.Gly.Ileu
Whale	..	..	CySO ₃ H.Thr.Ser.Ileu

The remainder of the A chain, and the whole of the B chain, are identical in all five species. This suggests that the exact structure of the residues in positions A8-11 is not important for biological activity, but it does not necessarily mean that all the rest of the molecule is essential. Clearly there is still much to be learnt on the question of insulin activity.

Since this was the first protein whose amino acid sequence had been completely determined, it was interesting to see if there were any general scheme underlying the sequence which might prove to be a general principle of protein chemistry. There appears, however, to be no such scheme. Individual residues do not occur at regular intervals along the chains. There are no small repeating units, nor any noteworthy concentrations of similar types of amino acids in any part of the molecule. In fact the arrangement appears to be a completely random one; it is nevertheless a very significant one, since on it depends in some way the unique biological activity of this hormone.

One significant result of this work is that it demonstrates that insulin, and probably other proteins, are homogeneous substances with unique structures and are not merely statistically random polymers of amino acids. This brings the science of proteins into the realms of classical organic chemistry and opens up the way to similar studies on the many other proteins that exist in nature and hence to a better understanding of the chemistry of life.

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Book reviews

KAYE AND LABY

Tables of Physical and Chemical Constants and some Mathematical Functions (*eleventh edition*), by G. W. C. Kaye and T. H. Laby. Pp. vi + 233. Longmans, Green and Company, London. 1956. 25s net.

'Kaye and Laby' needs no introduction, for since its first edition was published in 1911 it has been found virtually indispensable by many generations of research workers and students. It is sad that neither of the original compilers is still with us, but they would surely approve this new edition, prepared by a small committee under the chairmanship of Professor N. Feather. Although there are, of course, many alterations in detail, and new developments have demanded the inclusion of tables which did not appear at all in earlier editions, the spirit of the original has been well preserved. In particular the 'brief résumés containing references to such books and papers as may profitably be consulted', which were such an important feature of earlier editions, have been retained. 'Kaye and Laby' remains an outstanding work of reference, and it is particularly pleasing to see that so important a book is offered at so reasonable a price.

TREVOR I. WILLIAMS

DESCRIPTIVE ASTRONOMY

Introduction to Astronomy, by Cecilia Payne-Gaposchkin. Pp. x + 508. Eyre and Spottiswoode Limited, London. 1956. 50s. net.

Though written primarily as a textbook for general courses in descriptive astronomy, the author hopes that this book will serve the purpose of introducing astronomy to the student of the liberal arts. Being herself interested in language, history, and literature she has been at pains to point out the many associations of astronomy with these fields. The book is therefore more readable than textbooks are apt to be, and it should appeal to the general reader who has some interest in astronomy. Little background in either mathematics or physics is required for reading it with profit.

Modern astronomy is to a very large extent concerned with the stars, their properties and constitution, their distribution, their association into clusters and galaxies, and their evolution,

whereas formerly the chief interest lay in the solar system and the explanation in detail of the motions of planets, satellites and comets. In most of the older textbooks, relatively small space is given to the stars. In this book the balance is redressed, the emphasis being on stars and stellar systems.

A very balanced account is given of the present state of astronomy. Many current ideas about the evolution of stars and galaxies and various cosmological theories are of a tentative nature and may have to be abandoned in whole or in part. Whether such tentative ideas should be incorporated into a textbook is questionable, but the author has been careful to state that some of the theories she describes may have to be discarded. When this is done, and provided the author is prepared to revise the book at fairly frequent intervals, no harm can result; it should be of interest to the student and general reader to learn about the trend of ideas.

The book is very well illustrated, with many plates and diagrams. The planetary photographs taken at the Lowell Observatory and the photographs of stars and galaxies taken with the 200 in. reflector are of special interest.

H. SPENCER JONES

DIFFRACTION GRATINGS

The Interference Systems of Crossed Diffraction Gratings. Theory of Moiré Fringes, by J. Guild. Pp. viii + 152. Oxford, Clarendon Press; London, Cumberlege. 1956. 25s. net.

Moiré fringes, so called from their resemblance to *moiré* or watered silk, are frequently observed when two similar and regular patterns are superposed. The fringes formed by comparatively coarse patterns such as those of sieves and printers' process screens can be explained by simple geometry, but those formed by the crossing of diffraction gratings have not hitherto been studied critically, although they were observed by Lord Rayleigh and used by Sir Thomas Merton for demonstrating grating errors.

Mr. Guild's monograph is thus an adventure into unexplored territory, and he has given us a masterly survey of its topography. He develops a perfectly general theory to account for moiré fringe formation with all kinds of gratings, whether they be of the coarse

'slit and bar' type or the finer 'furrowed' type, and shows how the fringes are formed by the interference of diffracted wavefronts. This interference can produce a very wide variety of fine patterns, depending upon the distribution of energy in the various orders of diffraction of the two gratings. The theoretical explanation is well supported by a series of photographs which deserve to be printed on a larger scale.

The book is thus an original presentation of the theory of a new branch of interferometry, and its readers will await with impatience Mr. Guild's promised sequel on its practical implications, particularly in the field of precise measurement.

L. A. SAYCE

LUMINESCENCE

Irradiation Colours and Luminescence, by Karl Przibram, translated and revised by J. E. Caffyn. Pp. xiv + 332. Pergamon Press Limited, London. 1956. 63s. net.

This expanded version of the 1953 German edition is of much historical interest. It assembles a large amount of information on naturally coloured minerals, and on related artificial effects in synthetic crystals. The descriptive matter is, however, often discursive and too detailed for easy reading. The translator has done much to modernize the book, but could hardly alter its somewhat old-fashioned tone, which will do little to inspire present-day users. Thus the treatment of luminescence relies too much on obsolete ideas; the many added references could evidently not be discussed adequately without much more space.

Part I discusses experimental methods, the production and removal of colour centres in synthetic crystals, and associated theory. Luminescence is considered chiefly as thermoluminescence of coloured crystals, and photoluminescence at centres generated by radiation. Part II describes natural minerals, especially rock salt and fluorite, with the general thesis that natural radioactivity causes the observed colorations. The most valuable sections are perhaps those on natural radioactivity, rare earth activators, and pleochroic haloes; also the reference list, which has about 1300 entries, from Herodotus to 1954. Very few mistakes in reference page numbers have been noticed, but many misprints occur in the book, mostly in authors' names.

S. T. HENDERSON

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RADIOACTIVE ISOTOPES

Peaceful Uses of Atomic Energy. Proceedings of the International Conference in Geneva, August 1955. Vol. XV: Applications of Radioactive Isotopes and Fission Products in Research and Industry. Pp. viii + 327. United Nations, New York; Her Majesty's Stationery Office, London. 1956. 54s. net.

Like all other volumes of these Proceedings, this is well edited and excellently produced. Even those who took part in the Conference may benefit from this edition, as it also contains the papers—half the total—which could not be read at Geneva. As might be expected there is not much entirely new material here, for publication of work on isotopes was never restricted and had been discussed at previous isotope conferences. Nevertheless, the 48 papers offered provide a representative survey, with little overlapping, of the uses of isotopes and fission products in the many diverse fields.

One-third deal with isotopes applied in research, such as in the study of chemical and catalysed reactions, analysis, absorption phenomena, autoradiography, and diffusion. The second part deals with isotopes in control and technology; its contents should be of great benefit to most industries. The final section deals with the application of fission products which are still in the research and development stage. The use of ionizing radiations in many fields is discussed, most emphasis being placed on the sterilization of food; practically all contributions in this field come from the United States.

This volume should prove a very good investment for any industrial research library.

H. SELIGMAN

PHYSICAL CHEMISTRY

Physical Chemistry, by N. K. Adam. Pp. xii + 658. Oxford, Clarendon Press; London, Cumberlege. 1956. 50s. net.

Professor Adam's book has been awaited with eagerness, for it is a long time since a university textbook of physical chemistry was published in Britain. As would be expected, it is first-class in its clarity and accuracy, and in particular the balance between experiment and theory is well held. There are many illuminating touches, such as the illustration of Euler's Theorem by the blending of white coffee, and the invention of the term 'chaperon effect' for the removal of surplus energy by a third body. Many sections have short historical introduc-

tions, which are excellent in scope and presentation.

The writer of a general textbook of physical chemistry has to decide the selection and arrangement of the topics, and the amount of space to be given to individual examples, matters on which any two teachers of chemistry are certain to disagree. It will seem wrong to many that this book contains only cursory references to modern quantum theory: thus the Schrödinger equation is not solved even for the simplest systems, though some classical derivations of moderate complexity are given in full. The quantum theory of specific heat is treated only qualitatively. The structure of solids is treated fully (50 pages), with many examples, while the whole of thermodynamics and statistical mechanics occupies only 73 pages, very few examples being given. Similarly, the number of examples given of photochemical reactions and of colloid behaviour may seem excessive for a book of this size.

R. P. BELL

CHEMICAL ENGINEERING

Mass-transfer Operations, by Robert E. Treybal. Pp. ix + 666. McGraw-Hill Book Company, London. 1955. 71s. 6d. net.

Manufacturing operations are commonly concerned with systems in which inter-related changes of physical state and chemical composition take place to the accompaniment of energy and mass transfers from one part of the system to another. The individual changes proceed at characteristic speeds determined by driving forces which in the case of energy transfers may be temperature differences and in the case of mass transfers concentration gradients. One of the aims of chemical engineering science is to determine the mechanism by which such changes take place and to assign quantitative values to them.

Professor Treybal's book is primarily written for students, and as such it presents clearly and simply the quantitative approach to mass-transfer operations. The first five chapters introduce diffusion and mass-transfer theory, on which the subsequent treatment of gas-liquid, liquid-liquid, and solid-fluid operations is based. Brief accounts of current practice in plant design are also incorporated which give reality to the theoretical treatment.

In spite of some misplacement of emphasis and some important omissions, the book is well balanced and comprehensive in scope. References to the literature are adequate and the

numerical examples carefully chosen to illustrate major principles.

D. M. NEWITT

CHROMATOGRAPHY

Gas Chromatography, by Courtenay Phillips. Pp. x + 105. Butterworths Scientific Publications, London. 1956. 25s. net.

The sweeping success of the method of gas-liquid chromatography introduced by Martin and James in 1952 has tended to obscure the fact that gas chromatography was successfully practised much earlier. This clear and balanced account by a pioneer in the field is therefore particularly welcome. Although the book is modest in size and in quality of production—more so than its price would indicate—it nevertheless contains a great deal of information and a bibliography comprehensive enough to meet the needs of the advanced worker. The scope of the method is clearly defined, and there is a clear description of the various experimental techniques in general use. Theoretical treatment is not detailed, but is sufficient for an understanding of what happens on the column.

TREVOR I. WILLIAMS

INORGANIC CHEMISTRY

Nouveau Traité de Chimie Minérale, Vol. I. Généralités, Air, Eau, Hydrogène, Deutérium, Tritium, Hélium et Gaz Inertes, edited by Paul Pascal. Pp. xii + 1101. Masson et Cie, Paris. 1956. Paper covers, Fcs 7500; cloth, Fcs 8400 net.

One cannot but admire the enterprise of those responsible for the *Nouveau Traité de Chimie Minérale*. When completed it will consist of nineteen volumes, to appear at intervals from 1956 to 1960. The editor will be assisted by a panel of experts who will deal with the chemistry of the elements in the light of modern ideas of atomic and molecular structure. Technical details of industrial processes will be kept in the background, as the editor considers that this information is already available in specialist publications. The basis of classification is essentially the Periodic Table. The first volume of the series contains a general introduction of some 384 pages dealing with general topics such as the use of diagrams in chemistry, the stable isotopes and the radioactive isotopes of the elements, the structure of the atom and important aspects of modern structural chemistry. The various chapters are illustrated

with excellent diagrams and the information is clear and concise. The remainder of Volume I is devoted to detailed accounts of air, water, hydrogen, deuterium, tritium, helium, and the inert gases. The factual matter chosen for presentation has been selected as critically as possible, and the same applies to the quantitative information. Particularly valuable are the references at the end of each chapter to original work. The reader will find a useful account of the achievements up to date in the subjects covered.

W. WARDLAW

LITHIUM ALUMINIUM HYDRIDE

Lithium Aluminium Hydride in Organic Chemistry, by V. M. Micovic and M. L. Mihailovic. Pp. xi + 193. Serbian Academy of Sciences, Belgrade. 1955. \$3 net.

Lithium aluminium hydride has a high available hydrogen content, and readily reduces many functional groups, usually without side reactions, in cold ethereal solution. It is still a matter for wonder that carboxylic acids and esters may be so reduced to primary alcohols, and that the conditions are so mild that racemization of optically active centres does not occur. It was first prepared by Professor Schlesinger and co-workers at Chicago only ten years ago, and its remarkable powers as a reducing agent were first described by Nystrom and Brown in 1947-48. Such, however, are its advantages over other reducing agents that it has now become the reagent of choice. The present monograph contains 1732 references up to October 1954.

This book will prove of great value to all who may wish to use lithium aluminium hydride. Five sections deal with the reagent and the conditions under which it is used; the next nineteen each describe the reduction of a particular group. Among these are carbonyl compounds, acids, esters, lactones, amides, epoxides, peroxides, nitriles, nitro, halogen, and sulphur compounds. Each section gives examples, generously illustrated with formulae and with copious references to the literature; the coverage appears to be complete. The book ends with a section on the mechanism of the reductions, a complete index of references, and a good subject index.

W. BAKER

NUCLEAR CHEMISTRY

Peaceful Uses of Atomic Energy. Proceedings of the International Conference in Geneva, August 1955. Vol.

VII, Nuclear Chemistry and the Effects of Irradiation. Pp. 691. United Nations, New York; Her Majesty's Stationery Office, London. 1956. 70s. net.

This volume reports 86 papers from the Geneva Conference of 1955 and the discussions which followed them. It must be regarded, therefore, as essentially a reference book for specialists. However, its main value may well be to workers in the field traditionally called Atomic Energy, who, while not specializing in nuclear chemistry, can benefit from the up-to-date review articles and the wealth of facts and figures so conveniently available. Chemists in general will welcome the survey of nuclear fission by Steinberg and Glendenin and the papers on the formation and chemical properties of the new elements (transuramics). Inorganic chemists will find cause to consult the paper on anion exchange by Kraus and Nelson. The Japanese papers on radioactive fall-out have significance apart from their radiochemical content. Specialists will perhaps be irritated by the choice of title and the curious mixture of contents. 'Nuclear Chemistry' and 'Effects of Irradiation' (meaning radiation chemistry) are very different subjects. Many papers fall in neither category; remote handling, laboratory design, chemical separations and chemical properties do not constitute nuclear chemistry merely because they discuss radioactive substances. Less specialized readers may, however, welcome the mixture.

F. BROWN

ORGANIC SYNTHESSES

Organic Syntheses, Vol. XXXV, edited by T. L. Cairns. Pp. vi + 122. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1955. 30s. net.

The present volume details the syntheses of 36 organic compounds. With the immense growth of organic chemistry in recent years it is to be expected that some of the preparations described will be of somewhat limited interest; the syntheses are, however, often important applications of new methods and reactions. On the other hand, several improved methods of making familiar substances are listed. The preparations indicate the availability of apparatus and chemicals in the American scene; spinning-band columns are used for relatively simple fractional distillations; molar quantities of starting materials appear to be easily available; one preparation involves a steam distillation in which 36 litres of water are collected.

The writing is, as usual in this series, clear and eminently suited to the purpose of the book. As in previous volumes, the printing, paper, and binding are excellent. The book is essential to any active organic chemical laboratory.

J. C. SMITH

COLLAGEN

The Chemistry and Reactivity of Collagen, by K. H. Gustavson. Pp. ix + 342, and The Chemistry of Tanning Processes, by K. H. Gustavson. Pp. ix + 403. Academic Press Inc., New York; Academic Books Limited, London. 1956. \$8 and \$9 net respectively.

In the first of these two books the author has used his extensive researches on collagen, in the form of hides and skins, to provide the background of a most able review of our knowledge concerning its structure and reactivity, which is of fundamental importance in biochemistry, medicine, and leather technology. The parts played by X-ray techniques, electron microscopy, and birefringence in revealing the structure of collagen are lucidly discussed, showing the developments since Astbury's first researches. Other chapters deal with the isoelectric points of collagen and its interaction with acids and bases. The relationship between the internal linking of the collagen molecule and its hydration is clearly demonstrated in considering Donnan and lyotropic effects. Very sound chapters discuss the thermal shrinkage of collagen and its relation to cross-linking reactions and also the inactivation of specific groups for studying its reactivity.

The second book, which is of less general interest, deals with the fundamental chemistry of tanning, but does not describe the changes which take place in hides and skins during their conversion into leather. Nevertheless, the chapters relating to the chemistry of chrome tanning, the effects of neutral salts and complexing agents, and the nature of the chrome-collagen compound are of outstanding merit. Much interesting information is given on vegetable tanning, but sufficient stress is not placed on the factors, such as buffer salts, which control the process. Syntan, aldehyde, quinone, oil and combination tannages are also discussed. The final chapter is a definite contribution to our knowledge of the occurrence and mechanism of tanning processes in the animal kingdom and is of importance to biological and medical science.

D. BURTON

JANUARY 1957

GEOCHEMISTRY

Physics and Chemistry of the Earth, Vol. I, edited by L. H. Ahrens, *Kalervo Ranhamma*, and S. K. Runcorn. Pp. viii + 317. Pergamon Press Limited, London. 1956. 55s. net.

This is the first volume of a new series which should be of particular interest to geophysicists and geochemists. There are eight articles which cover a wide variety of topics, each reviewed in a general, rather than a specific, way. To a fairly well read geophysicist or geochemist this particular volume will not reveal much that is new, but it will be a valuable reference work, as each contributor cites many sources and provides a good bibliography.

Sir Harold Spencer Jones gives a short summary of the various theories of the origin of the solar system, from those of Kant and Laplace to the latest ideas of Alfvén and Kuiper. An interesting account of the most recent ideas and facts concerning the thermal state of the interior of the Earth has been written by J. Verhoogen. This article is complemented by K. E. Bullen, who reviews the general structure of the Earth's interior with particular reference to the density distribution. L. H. Ahrens discusses the various isotope-ratio methods for determining geological age, including the most recent work on potassium-argon, strontium-rubidium, and lead isotopes. R. Hide discusses the hydrodynamics of the Earth's core, with particular reference to the possibility that fluid motions are responsible for the Earth's magnetic field. R. Roy and O. F. Tuttle have written about the results of experiments carried out under hydrothermal conditions, which should be of special interest to the mineralogist and geologist. C. W. Correns describes the work on the geochemistry of the halogens, while S. I. Tomkeieff has produced an extensive review and bibliography of recent geochemical work in the Soviet Union.

P. M. DU BOIS

PROTOPLASM

The Dynamics of Living Protoplasm, by L. V. Heilbrunn. Pp. vii + 327. Academic Press Inc., New York. 1956. \$6.50 net.

Dr Heilbrunn has spent a lifetime in the study of protoplasm. The first of his papers which he quotes appeared in 1915, and dealt with the physical changes induced in sea-urchin eggs by the methods which lead to artificial

parthenogenesis; some of his most recent, written in collaboration with W. L. Wilson, are concerned with essentially the same subject, the changes in the egg cytoplasm during maturation. He has summarized in this book the fruits of the whole of this long period of intensive study of the colloid chemistry and physical properties of protoplasm as it is found in a wide variety of living cells. The book is a highly personal one: it was, as he points out, largely written in the laboratory at intervals between experiments, and perhaps it bears some traces of having been put together from a series of notes. Nearly the whole of it is devoted to expounding and defending his own rather unconventional views. As is well known, he attributes particular importance to reactions which he claims to be of the same nature as the clotting of blood, and which are mainly dependent on the state of the calcium in the system; in these terms he advances explanations of many of the major phenomena seen in living cells. While it is unlikely that many people will accept all his conclusions, it is valuable to have a full discussion of the whole range of his experimental work and the theories he has derived from it.

C. H. WADDINGTON

ENZYMES AND METABOLISM

Enzymes and Metabolism. Pp. 287. Elsevier Publishing Company, Amsterdam; Cleaver-Hume Press Limited, London. 1956. 47s. 6d. net.

This collection of 32 original papers is dedicated to Carl F. and Gerty T. Cori on the occasion of their 60th birthday. At least one of the authors of each paper is, or has been, at the Coris' laboratory. An introduction by Professor Houssay gives a fascinating account of the Coris' scientific activities during the last 35 years. Though the continuous theme of the study of carbohydrate metabolism runs through all their researches, they approached this with a tremendous versatility ranging from physiological work on whole animals, via the study of isolated tissue and of crystalline enzymes, to the chemical characterization of metabolites.

This collection of papers reflects the Coris' activities and covers a very wide range of subjects. Many of them are progress reports of work which was begun or at least inspired in the St Louis laboratory. Biochemists will wish to read most of them. H. GUTFREUND

PLANT PROTECTION

Bibliographie der Pflanzenschutzliteratur, 1951, edited by J. Bärner. Pp. xlv + 420. Published by Paul Parey, Berlin, for the Biologische Bundesanstalt für Land- und Forstwirtschaft in Berlin-Dahlem. 1955. DM. 38.

This bibliography of literature on plant protection for 1951 continues the well known series which ran from 1914 until 1945; volumes for 1946-50 have yet to appear. Its 12 500 titles certainly include all but a few of the works published in that year, but the accessibility of the information is not all that could be desired. There is an author index, but in the absence of a detailed subject index, reliance must be placed on headings under which the titles are grouped. These are well classified for general purposes. The main sections cover general questions, organisms and causal agents of disease subdivided into orders and families, host plants and their parasites, and control measures. Grouping in this way makes it easy to find all the references, say, to Cruciferae as weeds or to therapy by mercurial derivatives. But it fails to provide specific information. It is not possible, for instance, to obtain references to a particular chemical compound, and to find a species of organism its systematic place must first be known. Nevertheless a work of this kind is always useful to the special librarian. The research worker who wants more specific or up to date information can get it from the numerous abstracting journals which, to some extent, have reduced the value of this bibliographic series.

E. J. MCNAUGHTON

MYCOLOGY

Biology of Root Infecting Fungi, by S. D. Garrett. Pp. xi + 293. Cambridge University Press, London. 1956. 30s. net.

This book is an excellent exposition of that stimulating approach to plant pathology which has been affectionately called 'Garrettism' by Dr Garrett's former pupils and friends. Dr Garrett sees root diseases not alone as interactions between two organisms but as the resultant of interaction within the matrix of interacting ecological factors. He writes with a hope of interesting biologists, not pathologists alone, and it is apparent from the way in which he takes field problems into the laboratory and laboratory results to the field that Dr Garrett has a courage and tenacity which many plant ecologists would do well to emulate.

There are some general concepts such as inoculum potential, mycelial momentum and competitive saprophytic ability which are formulated and defined in this book. The definitions make use of such phrases as 'energy of growth', 'effective mass', 'summation of physiological characters' which, even if they are not quite scientifically precise and acceptable, are graphic in conveying the desired meaning. The reader will gain a great deal in the effort of trying to redefine these concepts in a more precise manner.

J. L. HARLEY

FUNGICIDES

Principles of Fungicidal Action, by James G. Horsfall. Pp. xix + 279. *Chronica Botanica Company, Waltham, Massachusetts; The Chronica Botanica Company, London.* 1956. \$6.50.

Much attention has been given in recent years to the relationship between chemical structure and fungicidal activity and to the mechanisms by which fungicides exert their effects. Dr Horsfall, who has played a conspicuous part in these investigations, now earns the gratitude of plant pathologists by reviewing the work that has been carried out and by summarizing the present position.

His book forms a natural successor to his earlier 'Fungicides and their Action'. The principles of the methods of assessing fungicidal activity are fully discussed, and attention is given to aspects of protection such as deposition and the mobilization of fungicide deposits upon plant surfaces. Other sections are devoted to the penetration of fungicides, to the effects of toxicants upon growth phenomena and fungus metabolism, to the chelation of metals, and to the mechanism of action of many kinds of established fungicides. The author's survey of the systemic treatment of plants and his warning of the probable development of resistant fungi are of particular interest.

The book is designed for the specialist and contains a wealth of information, particularly on the types of compound that show activity. It is perhaps marred somewhat by doubtful generalizations and loose phraseology, and by fanciful attempts at popularization that seem out of place in a work of this nature.

J. T. MARTIN

METABOLIC PROCESSES

La Régulation des Processus Métaboliques dans l'Organisme, by Théophile

Cahn. Pp. xii + 681. *Presses Universitaires de France, Paris.* 1956. Fcs 3000.

This book sets out to discuss the hormonal control of the metabolic processes concerned with the supply of energy. The introductory chapter describes the endocrine disorders which can be produced experimentally by removal of the endocrine tissues, or by specific poisons such as alloxan. The next chapter—more than half of the book—deals with the transport of metabolites and its control by hormones. This covers the physiology of the blood sugar, of fat absorption, of blood lipids, of the nitrogenous substances, and very briefly of inorganic salts and water. Then follows a description of the physiology of energy release and of the interconversion of carbohydrate, fat, and proteins. The role of the nervous system in the control of metabolism, though briefly mentioned, is not discussed.

The approach throughout is that of the classical physiologist. Only occasionally is reference made to details of intermediary metabolic processes, and enzymes are hardly mentioned, not even in connection with the mechanism of action of insulin. In his preface the author points out that this limitation is deliberate. The book centres round the author's own research experience during the past 25 years, and as a coherent record of his viewpoint it is certainly a valuable addition to the literature.

H. A. KREBS

NUCLEAR REACTORS

Principles of Nuclear Reactor Engineering, by Samuel Glasstone. Pp. ix + 861. *Macmillan and Company Limited, London.* 1956. 60s. net.

This authoritative work, sponsored by the United States Atomic Energy Commission, is an important addition to the growing volume of literature for engineers in the nuclear energy field; it is intended both for practising engineers and for senior or post-graduate engineering students. Dr Glasstone had the assistance of staff of the Oak Ridge National Laboratory, and has given a broad and comprehensive review of the scientific basis of reactor design, construction, and operation.

About one-third of the book is devoted to the fundamental physics of reactors, with chapters on the relevant aspects of nuclear reactions and radiations and on reactor theory in equilibrium and non-equilibrium conditions. Specific aspects of reactors are then

treated in turn: instrumentation and control, chemical processing of fuel, materials, radiation protection, shielding, and heat generation and transfer. There is a chapter on design variables, in which many of the possible types of reactors are discussed, and a series of descriptions of particular installations.

The material is excellently arranged. Each chapter is followed by definitions of the symbols used in the text, and by a set of problems. There are many references and suggestions for more detailed reading, and a good index.

T. G. PICKAVANCE

REACTOR TECHNOLOGY

Peaceful Uses of Atomic Energy. Proceedings of the International Conference in Geneva, August 1955. Vol. IX, Reactor Technology and Chemical Processing. Pp. x + 771. *United Nations, New York; Her Majesty's Stationery Office, London.* 1956. 70s. net.

This volume is predominantly of interest to the chemist and metallurgist. It deals with the metallurgy and fabrication of fuel elements, with liquid-metal heat-transfer media, and with the chemical aspects of atomic energy such as corrosion, processing of fuel and fission products, and waste disposal problems.

This is one of the most important volumes of the Geneva Conference series. Nearly all the material presented had been treated as secret almost up to the date of the conference, while the cost of the research and development described must have been some tens of millions of pounds. For this reason the origin of the papers is of some significance: 53 from the United States, 16 from Great Britain, 16 from the rest of Europe, only 3 from the U.S.S.R.—an insignificant proportion compared with the Soviet contribution on less secret subjects such as radiation studies and isotope research.

To the scientist or technologist concerned with atomic energy almost all the papers are of the greatest value. But a large number of new fields have been explored, such as the chemistry and metallurgy of some rarer elements, new methods of chemical analysis, and new chemical engineering techniques, particularly for the separation and purification of inorganic salts by solvent extraction. Many of these unconventional treatments, now that they have been developed, can with advantage be applied to other branches of research and industry.

E. GLUECKAUF

Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books discussed.)

Elementary Wave Mechanics (second edition), by W. Heitler. Pp. viii + 193. Oxford: Clarendon Press. London: Cumberlege. 1956. 18s. net.

This is a second edition of a book for non-mathematical readers the success of which is indicated by the fact that it has been five times reprinted since it first appeared in 1945. The new edition includes a section on diatomic molecules, and the chapters on the chemical bond have been much extended. A section on the time-dependent wave equation has also been added.

Physical Chemistry (second edition), by W. J. Moore. Pp. xii + 633. Longmans, Green and Company, London. 1956. 30s. net.

This textbook of physical chemistry, first published in 1950, is designed for students of science and engineering. It is rather more than an elementary work, and assumes in the reader a knowledge of calculus and some two years' systematic study of both physics and chemistry. This new edition follows the general lines of the first, but there have been in every chapter corrections of detail and changes in presentation. A new chapter on photochemistry has been added, and recent advances in nuclear, atomic, and molecular structure are described.

Cumming and Kay: 'Quantitative Chemical Analysis' (eleventh edition), revised by Robert Alexander Chalmers. Pp. xvi + 540. Oliver and Boyd, Edinburgh. 1956. 30s. net.

This well known textbook of quantitative chemical analysis, now in its eleventh edition, is designed primarily for the use of university students. The last edition appeared in 1948, and this new one represents a thorough revision. Major alterations include the rewriting of the section on colorimetry and the addition of a short account of the theory of precipitation and contamination of precipitates. An innovation is the inclusion of short reading lists.

Organic Chemistry (third edition), by Louis F. Fieser and Mary Fieser. Pp. v + 1112. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1956. 50s. net.

This is the third edition of a well known textbook of organic chemistry,

which has been thoroughly revised—and in many parts rewritten—to take note of the many new enlargements in both theory and practice that have taken place since the second edition appeared in 1950. The number of reaction mechanisms considered has been increased, and each is discussed as the reaction is encountered in the text. A feature of the book, adapted from the German translation of the second edition, is the inclusion of some 450 brief biographical sketches of the principal chemists, past and present, whose work is discussed.

Essays in Biochemistry, edited by Samuel Graff. Pp. x + 345. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1956. 52s. net.

These twenty-seven essays, covering a wide field, were written in honour of Hans Clarke, by some of his former students and academic associates, on the occasion of his retirement. They are in the main neither reviews nor experimental reports. Some are critical assessments of contemporary biochemical problems, others are frankly speculative: all are authoritative and include extensive bibliographies.

Learning and Instinct in Animals, by W. H. Thorpe. Pp. viii + 493. Methuen and Company Limited, London. 1956. 55s. net.

In recent years ethological research workers have tended to follow one or other of two quite distinct lines. Either instinct has been studied, especially in Europe, or learning, especially by American workers using laboratory-bred animals. This book represents an attempt to integrate these two different methods of approach to the subject. The first part of the book deals with general principles. The remainder surveys the part played by learning in the organization of the behaviour of the principal groups of animals, from the Protozoa to the Mammals.

The Private Life of Fishes, by M. Constantin-Weyer (translated by R. Turrell). Pp. 149. Richard Bell, London. 1956. 15s. net.

This is a discursive account of the life and habits of fishes, written in a popular style and intended primarily for the naturalist and angler but suitable also for the general reader. Among the

topics discussed are the breeding, growth, migration, and vision of fishes.

Histamine: Ciba Foundation Symposium, in honour of Sir Henry Dale, edited by G. E. W. Wolstenholme. Pp. xvi + 472. J. and A. Churchill Limited, London. 1956. 50s. net.

This book is the edited record of papers read and discussions held by an international gathering of physiologists and pharmacologists in London in 1955. It is divided into two parts. First, the proceedings of a symposium organized jointly by the Physiological and the Pharmacological Societies; second, a less formal symposium on the same subject sponsored by the Ciba Foundation. It deals comprehensively with current research developments in the study of histamine and related substances.

Internal Secretions of the Pancreas: Ciba Foundation Colloquia on Endocrinology, Vol. 9, edited by G. E. W. Wolstenholme and Cecilia M. O'Connor. Pp. xii + 292. J. and A. Churchill Limited, London. 1956. 40s. net.

This is an account of the proceedings of a colloquium on internal secretions of the pancreas, organized by the Ciba Foundation and held in London in June 1955. It includes both the text of the seventeen papers read and a full account of the discussion which followed each of them. The papers cover a wide field, and the volume should prove of interest to medical research workers, biochemists, and biologists.

High-temperature Technology, edited by I. E. Campbell. Pp. xiv + 526. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1956. 120s. net.

A symposium on 'High-temperature materials, methods, and measurements', organized by the Electrochemical Society in Washington in 1951, indicated the need for a comprehensive work on high-temperature technology. This book, the joint effort of thirty-five contributors, is designed to meet this need. It describes new materials, methods of production, and the measurement of physical properties. In general, high temperatures are taken in the present context to be temperatures above 1500° C.

Notes on contributors

F. P. BOWDEN,
C.B.E., Sc.D., F.R.S.,

Was born in Tasmania in 1903 and became Demonstrator in Physics, University of Tasmania. In 1927 he came to Gonville and Caius College, Cambridge, of which he is now a Fellow; he is Director of Studies and University Reader in Physical Chemistry. During the last war he worked for the Australian Government, and in Melbourne at the Tribophysics Laboratory of the Commonwealth Scientific and Industrial Research Organization. His researches have dealt with the properties of metals and of solid surfaces and with decomposition in the solid state. He has published 'The Friction and Lubrication of Solids' (with D. Tabor) and 'The Initiation and Growth of Explosion in Liquids and Solids' (with A. Yoffe). He is Vice-President of the Faraday Society and was recently awarded the Redwood and the Cresson Medals of the Franklin Institute for his work on friction.

N. MILLOTT,
M.Sc., Ph.D.,

Was born in 1912 and studied at the Universities of Sheffield, Manchester, and Cambridge. From 1938 until 1947 he held an appointment as Lecturer in Zoology in the University of Manchester. In 1948 he was appointed to the Chair of Zoology in the then newly created University College of the West Indies, resigning in 1955 on appointment to a Chair of Zoology in the University of London, tenable at Bedford College. His earliest research dealt with the digestive system of nudibranch molluscs, followed by work on the nervous control of the viscera in *Lumbricus*. For the past eight years he has studied the sensitivity to light and the pigmentation of various ani-

mals, especially echinoids. During this time he has held both Carnegie and Guggenheim Fellowships in the United States.

E. N. DA C. ANDRADE,
D.Sc., Ph.D., LL.D., F.R.S.,

Was born in London in December 1887 and was educated at St Dunstan's College, the Universities of London, Manchester, and Heidelberg, and the Cavendish Laboratory, Cambridge. He served as an artillery officer in France in the war of 1914-18, and afterwards was for some years professor at the Artillery College (later the Royal Military College of Science). In 1928 he was appointed Quain professor of physics in the University of London. At University College he established a flourishing school of physics, known for fundamental work on the mechanical properties of the solid and liquid state. In January 1950 he was appointed Director in the Royal Institution of Great Britain and Director of the Davy Faraday Research Laboratory, but in 1952 resigned, like his predecessor. He maintains close connection with colleagues overseas, and is *Membre Correspondant de l'Académie des Sciences, Institut de France*. He is known for the clarity of his exposition of science, both in writing and by lectures.

J. M. M. PINKERTON,
M.A., Ph.D.,

Was born in London in 1919 and educated at Clifton College and Trinity College, Cambridge. During the last war he was employed on government radar projects at the Telecommunications Research Establishment in Swanage and Malvern. He returned to Cambridge in 1945 to do research in ultrasonics at the Cavendish Laboratory. Since 1949 he has been in charge of the engineering development of the electronic com-

puters LEO I and LEO II. His publications include various papers on ultrasonic absorption in liquids and on electronic computers.

JAMES PATON,
M.A., B.Sc., F.R.S.E.,

Was born in 1903 and educated at Beath High School and Edinburgh University. After a year in the Meteorological Office he became lecturer in the Department of Natural Philosophy, Edinburgh University, in 1928, senior lecturer in 1950, and reader in 1954. He is correspondent for Section IV (Aurora and Airglow) of the British National Committee for the International Geophysical Year, and Director of the Aurora and Zodiacal Light Section of the British Astronomical Association.

F. SANGER,
B.A., Ph.D., F.R.S.,

Was born in 1918 and was educated at Bryanston School and the University of Cambridge. Since graduating in 1939 he has carried out research in the Department of Biochemistry, Cambridge. From 1944 until 1951 he held a Beit Memorial Fellowship for Medical Research and since 1951 has been a member of the external staff of the Medical Research Council. His work has been largely concerned with the chemical structure of proteins, especially of insulin.

L. F. SMITH,
Ph.D.,

Was born in 1927 and was educated at Bede Grammar School, Sunderland, and Imperial College, London. Carried out research on wool chemistry at Imperial College before moving to the Department of Biochemistry, Cambridge, where he is now working as a member of the external staff of the Medical Research Council.

ENDEAVOUR

A quarterly review designed to record the
progress of the sciences in the service
of mankind

VOLUME XVI

April 1957

NUMBER 62

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Towards a unity of knowledge

The aphorism *tempora mutantur nos et mutamur in illis* has lost none of its truth with the passing of the centuries, but it is disturbingly evident that its lesson is not being applied today. Within the past century man's whole way of life has been changed, mainly through scientific discovery and its application, but it would be idle to assert that civilization has adequately adapted itself to the new conditions. It would, indeed, be surprising were it otherwise, so headlong has the pace of material development become, but one may nevertheless ask whether we are not being too much swept along by the technical changes of the age and making too little effort to change our ideas to accord with them.

It is argued that the deep differences which so unhappily divide the world today spring in large measure from the fact that man's moral stature has not increased in proportion to his sudden great access of material power and wealth. While this is certainly true, what seem to be moral problems often have material roots without which they would not arise. Poverty, famine, and pestilence are among great material evils which tend to find irrational outlet in oppression or violence excused as the righting of moral wrong. It would be an ill world if all standards were material, but it would be a better world if all basic material wants—food, clothing, housing, health—were satisfied. To this goal of satisfying material wants the intensive application of science seems by general consent to be our most hopeful route.

If this thesis be accepted, it follows that we require the widest and most rapid dissemination of knowledge of new scientific and technical advances, so that it can be turned to practical account with the least possible delay, and a general appreciation of both the nature and importance of science and technology. It cannot be said that the present organization for effecting this is satisfactory; far more serious, it cannot even be said that the grave dangers arising from its shortcomings are generally appreciated by those who determine policy.

How the problem is to be solved is very far from clear, but a prerequisite to any attempt is recognition of its gravity and of the fact that we must be prepared to make far-reaching changes. While the nature of the changes necessary is very controversial, not least because every country and every class has its own problems, some points seem to have gained a fair measure of acceptance.

Basically, it is agreed, the problem must be one of education, a process which in its widest sense goes on throughout life but whose main pattern has generally to be established in the early formative years. Here two opposing tendencies must be reconciled. On the one hand, the development of civilization as we know it today depends on the availability of large numbers of people having advanced technical knowledge: as economic and other factors strictly limit the number of years that can be given to formal education, a corollary of this is that each of these people must specialize at a fairly early age and thus have correspondingly little time for the study of what are broadly called the humanities. This is a most serious loss, for humanizing influences are not so abundant in the world that we can afford to diminish them. On the other hand, education based on the humanities alone is on many counts quite inappropriate to the times in which we live. In short, how can science be infused into the humanities, and the humane studies into science, without so diluting either that their savour is lost?

It does not seem that the gap is unbridgeable. Part at least of the difficulty appears to lie in the tendency to look upon science and the humanities as two quite separate entities, which may perhaps be studied side by side but yet have nothing in common. If this premise were discounted, however, and it could be accepted that the two were different parts of one vast field of learning, the consequences might be far-reaching. A century ago the immense learning represented by the humanities far exceeded that represented by science; since then the humanities have made relatively slow progress, whereas science has advanced with giant strides. A union of the two would be a formidable combination.

There is some evidence, at least, that such a synthesis need not be an idle dream. Within science itself there is occurring a process of unification that might have seemed no less difficult only a few decades ago. During the greater part of the nineteenth century science advanced along three major but apparently steadily diverging routes—physics, chemistry, and biology. Now the process of divergence has greatly diminished, and among the most fertile fields are those in which several branches of science have combined. While the specialist is more essential than ever, narrow specialization seems to be paying diminishing

dividends, although there must always be a place for the individual with a flair for it. Again, the once important distinction between pure and applied science is increasingly being seen to be an artificial one. The problems posed in the application of science need be intellectually no less challenging than those encountered in the pursuit of scientific knowledge for its own sake. The Grecian concept that practical matters were necessarily on a low intellectual plane, and unworthy of the attention of free men, can be seen in retrospect as a fatal defect, but it could equally well be the downfall of our own civilization.

That some similar unification of science with the humanities is possible seems arguable on sounder grounds than those of mere analogy. Archaeology, for example, has been infused with new life by the adoption of a wide range of scientific techniques, and now provides ground on which scientist and classic can meet on equal terms. History, which has successively extended its boundaries to include political, social, and economic history, is now extending them further to include the history of science and technology, long studied largely in isolation. Problems of philosophy and religion are increasingly engaging the attention of those primarily trained as scientists.

It would be unrealistic to suggest that such tenuous links themselves herald the opening of a new age, but they surely indicate possibilities well worth cultivating. Any unification of modern knowledge must be a tremendous and increasingly difficult task, both because of the vast amount of material to be considered and because of the many unfilled gaps. Scarcely less great would be the task of distilling from it a pattern of general education which would both reflect the unity and yet be sufficiently flexible to cater for the diverse practical needs of the nations of the world and the widely varying abilities and aspirations of individuals. But the obvious weaknesses of traditional systems, and the unbalance that results from excessive concern with purely technical subjects in education, alike urge the need for a radical revision of ideas.

Such a synthesis would have far-reaching practical, as well as cultural, effects. Although scientists form an important and influential group,

there is still much prejudice against their participating in the wider fields of human affairs. Such participation is becoming increasingly necessary, and is slowly being achieved, but it is certainly not justified merely by the possession of advanced scientific knowledge. Wider knowledge and experience are essential to the scientist if he expects to be more than a technical adviser. Equally, however, the organization of science is now so complex that administrative problems have become of serious consequence, and administrative ability does not, and need not, go hand in hand with a marked talent for science. If it is to be exercised in the scientific field, however, where there is great and increasing need for it, some background of technical knowledge is clearly very desirable. This again emphasizes the need for an educational system which provides some common ground on which scientist and non-scientist can meet.

The establishment of such a common ground clearly ought to be the result of moves from both sides, but at the moment the initiative is very largely with scientists, many of whom have clearly demonstrated their ability to assist in the formulation of policy and to undertake administration at the highest levels. Unfortunately, the reverse process is still an almost completely forbidden transition, and in the present state of affairs this is understandable: policy decisions tend to be the responsibility of older men in established positions, who naturally cannot enter upon a course of scientific study detailed enough to be helpful in taking decisions relating to scientific matters. An education which included some serious study of science would, however, be a great aid to judgment.

Whether knowledge is taken to be desirable for its own sake or for the material benefits it can confer—and most people now would consider it to be desirable for both these reasons—the argument in favour of trying to effect some synthesis of science and the humanities seems to be unanswerable. From it might well stem consequences as far-reaching as those which have resulted from the recent cross-fertilization of the different branches of science, which were for so long thought necessarily committed to different paths of development.

Nuclear reactors for the generation of electrical power

SIR CHRISTOPHER HINTON

Britain is the first country in the world to have established a full-scale electrical generating station powered by nuclear energy. Three much larger stations are already under contract for the Central Electricity Authority, in addition to three dual-purpose stations under construction for the Atomic Energy Authority. This authoritative article reviews the principal factors which led to the choice of the graphite-moderated gas-cooled reactor for Calder Hall; it is predicted that under the conditions which exist in Britain and some, but not all, other countries, this type of reactor will continue to be the most suitable for electrical power stations for at least the next fifteen years. The future of more advanced types of reactors is also discussed, with special reference to the Dounreay fast reactor prototype.

The only nuclear reaction which in the light of present knowledge can be used to release heat convertible into electrical power is that in which fission takes place in one of the heavy elements at the top of the periodic table. In nature only one fissile atom exists, the isotope of uranium having an atomic mass of 235. It follows that any programme for the industrial generation of nuclear power must initially be based on the use of uranium as fuel.

When fission takes place in U^{235} , heat is released; fission products are formed which may include almost any of the elements in the middle of the periodic table; and on an average rather more than $2\frac{1}{2}$ neutrons are emitted. In order to maintain a chain reaction, at least one of these neutrons must be used to cause a further fission; the others may be absorbed either usefully or uselessly. For power generation, the amount of useless absorption must obviously be kept to a minimum, and this is done by excluding impurities which give rise to such absorption. Useful absorption must be by atoms which as a result form daughter products which can be employed in subsequent processes.

When natural uranium is used as a fuel in a nuclear reactor, the most important absorbing material present in the assembly is U^{238} . By neutron absorption this atom forms an unstable isotope which subsequently decays to form plutonium, which, like U^{235} , is fissile. The chain reaction involved in this process is shown in figure 1.

The fissile isotope exists to the extent of only 0.7 per cent in natural uranium; the remaining 99.3 per cent consists almost entirely of the non-fissile U^{238} isotope. Natural uranium can be en-

riched in respect of the fissile isotope by treatment in a gaseous diffusion plant, but this is an expensive process which demands the use of electrical power in very large quantities. It follows that in the initial stages of a nuclear power programme it is desirable to use natural uranium, or at any rate uranium which has been only slightly enriched in respect of the fissile isotope.

MODERATORS

The number of atoms of U^{238} which are available as targets for the neutrons released far exceeds the number of targets provided by the atoms of U^{235} , and the laws of probability would therefore determine that most of the neutrons emitted would be absorbed in atoms of U^{238} and few of them would strike atoms of U^{235} to cause further fissions. In these conditions the chain reaction would not be maintained. The probability of a neutron causing fission in an atom of U^{235} can, however, be increased, and the probability of its being absorbed in an atom of U^{238} correspondingly reduced, if the neutrons are slowed down from their initial high velocities to thermal velocities by allowing them to share their energy with other atoms before striking the atoms of uranium. The material used for thus reducing the velocity of neutrons is called a moderator, and the atoms most suitable for use as moderators are those of hydrogen, heavy hydrogen, beryllium, and graphite. Reactors in which neutrons are reduced to thermal velocities before use are called thermal reactors. The atoms of the moderator in which the uranium fuel elements are arranged in a calculated lattice can, of course, be in chemical combination with other atoms, but such atoms as are

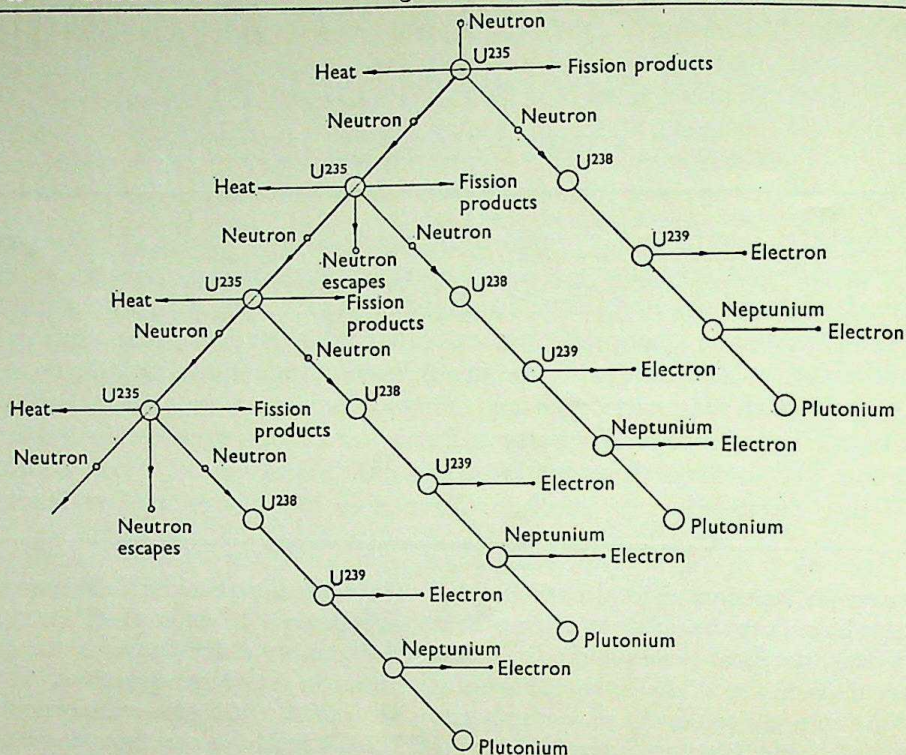


FIGURE 1 - Chain reaction in a nuclear reactor.

introduced in chemical combination with the moderator must not uselessly absorb neutrons.

When carbon is used as the moderating atom it is normally in the form of graphite, both because the graphitization process removes some of the impurities which it would otherwise be difficult to eliminate and because the physical and mechanical properties of graphite make it the most suitable form of carbon from the engineering point of view. Hydrogen can be used as a moderator either in combination with oxygen as water, or in the form of a hydrocarbon. Heavy hydrogen is usually used in the form of heavy water. Beryllium has generally been considered in the form of beryllium oxide.

Each of these moderators has its own advantages and disadvantages. Graphite of suitable purity is reasonably readily available, is not unduly expensive, and has fair neutron economy. It has the disadvantage that it starts to be chemically reactive with many other materials at temperatures of 500–600° C, and so imposes additional limitations on the materials which can be used in graphite-moderated reactors designed to operate at these or higher temperatures. It has the further disadvantage that it is bulky, making it difficult to construct compact graphite-moderated reactors.

Hydrogen in the form of water has the advan-

tage of ready availability and low cost, but the disadvantage that, at the temperatures and purities which must be achieved in an atomic pile, it is highly corrosive to most materials of construction and would react rapidly with the uranium of the fuel elements if defects occurred in the protective sheath which surrounds this uranium. The use of water as a moderator has the further disadvantage that at the temperatures which must be achieved in power-producing reactors a high pressure must be used if it is to be prevented from boiling. In certain designs this would involve the use of heavy pressure shells, which would place an upper limit on the size of reacting core which could be employed. Water has too the disadvantage of a poor neutron economy, and it is not possible to design a reactor using water as a moderator which can employ natural unenriched uranium as its fuel. Some of these drawbacks can be avoided if the hydrogen is used in the form of a hydrocarbon, but in the past this has presented a difficulty in that under neutron irradiation most hydrocarbons are unstable and tend to form sludges. It should not be assumed, however, that this difficulty is insuperable.

Deuterium is normally used as a moderator in the form of heavy water, and in this form it has many of the disadvantages associated with hydrogen

when used in the form of ordinary water. It had in the past a further disadvantage that its price was very high, and it was not readily available. In recent months, however, the United States has offered to sell heavy water at prices far below those which were previously considered normal. This possibility of lower manufacturing cost considerably improves the prospects for the use of deuterium. From the point of view of neutron economy, heavy hydrogen is better than any other moderator, and this is an immense advantage.

Beryllium, used in the form of beryllium oxide, has the great attraction of high chemical and thermal stability. By using this material as a moderator it would be possible to achieve temperatures which do not appear to be within the bounds of possibility with the other moderators that have been considered. Its neutron economy is similar to that of graphite. On the other hand, beryllium is not readily available and the present cost is high.

COOLING FLUIDS

Besides the fuel element and the moderator, the remaining essential component of the core of a reactor is the coolant, and the choice of the fluid for this purpose is important in relation to the stability, and therefore the safety, of the reacting system. If in the design adopted the coolant is more effective as a neutron absorber than it is as a moderator, then the reactor may have an inherent instability. Consider, for instance, a reactor using graphite as a moderator and water as a coolant, and assume that the fuel elements are in the form of natural uranium rods lying in a tube through which the water flows. To some extent this water acts as a moderator, but its more important effect in determining the nuclear physical characteristics of the reacting core lies in the fact that it absorbs neutrons. If as a result of mechanical or electrical failure the flow of cooling water were stopped, the heat emitted from the fuel elements would be great enough to vaporize the water in the cooling annulus, and this water would be ejected from the tubes as steam. Far fewer atoms of water would then surround the fuel elements than in the normal working condition, and there would therefore be less absorption of neutrons in this water annulus. Unless the mechanically operated safety devices on the reactor worked instantaneously, the neutrons which were previously absorbed in the coolant would become available to cause further fissions. The

activity of the pile might in these circumstances increase to the point where the core melted and collapsed. Avoidance of this instability is a major question in the choice of coolant and in reactor design. Apart from this important limitation, any gaseous or liquid coolant can be chosen, provided it is not a heavy neutron absorber and that its chemical and physical properties are suitable.

Gaseous coolants, in general, have a small neutron absorption cross-section and the advantage that they do not give rise to instability of the type just discussed. It is also possible to choose gases having other characteristics which make them suitable for use in a reactor. All gases, however, have the disadvantage of low heat capacity, and the power required for circulating them is therefore considerable. Of the possible gases, carbon dioxide is cheap, has reasonable stability, and is not particularly corrosive. Helium is completely inert, and this removes many of the metallurgical problems of design: it is, however, expensive and, from the British point of view, has the serious disadvantage that large supplies are available only from America. From the point of view of physical properties hydrogen is ideal, as it has very much better heat-transfer properties than either helium or carbon dioxide, but the use of hydrogen in high-temperature nuclear reactors introduces very serious metallurgical problems.

Liquid coolants have very much better heat-transfer characteristics than gases, and with them it is therefore possible to achieve considerable economies in the power required for circulating the coolant. It is also possible to achieve very much higher ratings, i.e. heat output per unit mass of fuel in the reacting core, when liquid coolants are used.

The liquid coolants most obviously suitable are water or heavy water, hydrocarbons, or liquid metals. Apart from the question of reactor stability, the use of water as a coolant has the technological disadvantages that were mentioned in connection with its use as a moderator. Hydrocarbons suffer from chemical instability under neutron irradiation. Among the metals, sodium and bismuth have a low neutron absorption cross-section and low melting points and appear to be the best coolants of this type.

It will therefore be seen that in making our selection of the best type of thermal reactor we have an embarrassing number of alternatives, since, in theory, any one of the possible moderators may be used in conjunction with any one of the possible coolants.

THE GRAPHITE-MODERATED GAS-COOLED REACTOR

In the light of these considerations it was, however, fairly easy to make the graphite-moderated gas-cooled reactor our choice for the first stages of the British Atomic Energy Programme. Neither heavy water nor beryllium was available as a moderator. When light water is used as a moderator the fuel elements must be of enriched uranium, and when our first reactors were built this was not available. Graphite could be obtained in suitable quality and quantity, and its neutron economy was such that it could be used with fuel elements made of natural uranium.

The reactors which had been built in America during the war for plutonium production had used graphite as moderator with water as coolant. It has already been pointed out that reactors built on this system are inherently unstable, and for this reason very large safety distances were adopted in choosing the location for the American installation. Such remote sites could not conveniently be found in Great Britain, and in spite of the fact that the rating that could be achieved would be lower and the design demanded higher capital stocks of uranium, it was decided to use air cooling on the initial Windscale piles. When these were built, the problem of removing the heat at a sufficiently high temperature for it to be used for power generation could not be solved sufficiently quickly, and the Windscale reactors built to produce plutonium for defence purposes were cooled simply by blowing air at atmospheric pressure over the fuel elements and wasting the heat to the atmosphere.

When, in the early 1950's, it was possible to consider the construction of reactors in which the heat of fission could be used for the generation of electrical power, it was found that the same major considerations still outweighed all others. Metallurgical research and operating experience with the Windscale reactors had made it possible to extract the heat at temperatures high enough to enable useful power to be generated through the medium of a steam cycle. Although enriched uranium was by then being produced in considerable quantities at the Capenhurst factory, this material was required for defence purposes and only limited quantities were available for research and for the industrial programme. It was therefore necessary to select a reactor which could use natural uranium as its fuel: the use of water as a moderator was thereby excluded. Neither heavy water nor beryllium was available, and so graphite was

the obvious material to choose as the moderator.

It was realized that in building a reactor which could be used industrially it was necessary to adopt a system for which inherent stability could be claimed, and this could most readily be achieved by using a gaseous coolant. It should be noted that by this time it had been realized that a stable system could be built using graphite as a moderator and water as a coolant, provided that the quantity of water in the cooling annulus was increased sufficiently to ensure that the water's effect as a moderator was as great as its effect as an absorber in the neutron balance of the pile. This additional quantity of water, however, could be introduced into the cooling annulus only if enriched uranium were used in the fuel elements, and, as already pointed out, this material was not available. Moreover, the use of water as a coolant would have introduced the metallurgical problems, already mentioned, of corrosion of the tubes and possible attack on the fuel elements.

Use of liquid metals as the coolant would also have demanded enrichment of the fuel elements, and at the time of which we are speaking the technology of the use of liquid metals was still presenting very considerable problems. It was, therefore, decided that the first British power-producing reactors should be built on the graphite-moderated gas-cooled system. Helium, with its advantages of complete chemical stability, was not available. Hydrogen presented problems arising from its reactivity with the materials of construction. Carbon dioxide, on the other hand, was cheap and sufficiently non-reactive at the temperatures under consideration to be completely suitable.

The Calder Hall reactors have been fully described elsewhere¹: their general design and appearance are shown in figures 2 and 7. The fuel elements consist of rods of uranium 1.15 inches in diameter enclosed in protective cans made of magnesium alloy and fitted with fins to increase their heat-transfer coefficient. These fuel elements stand in vertical channels within the mass of graphite moderator. In order to improve the cooling capacity of the carbon dioxide and reduce the amount of power required for circulation, the whole system is put under a pressure of 7 atmospheres. To achieve this it is necessary to enclose the whole of the reacting core in a steel vessel 37½ feet in diameter and 70 feet long, the thickness of the walls being 2 inches. The gas is circulated

¹See, for example, JAY, K. 'Calder Hall,' Methuen, London, 1956.

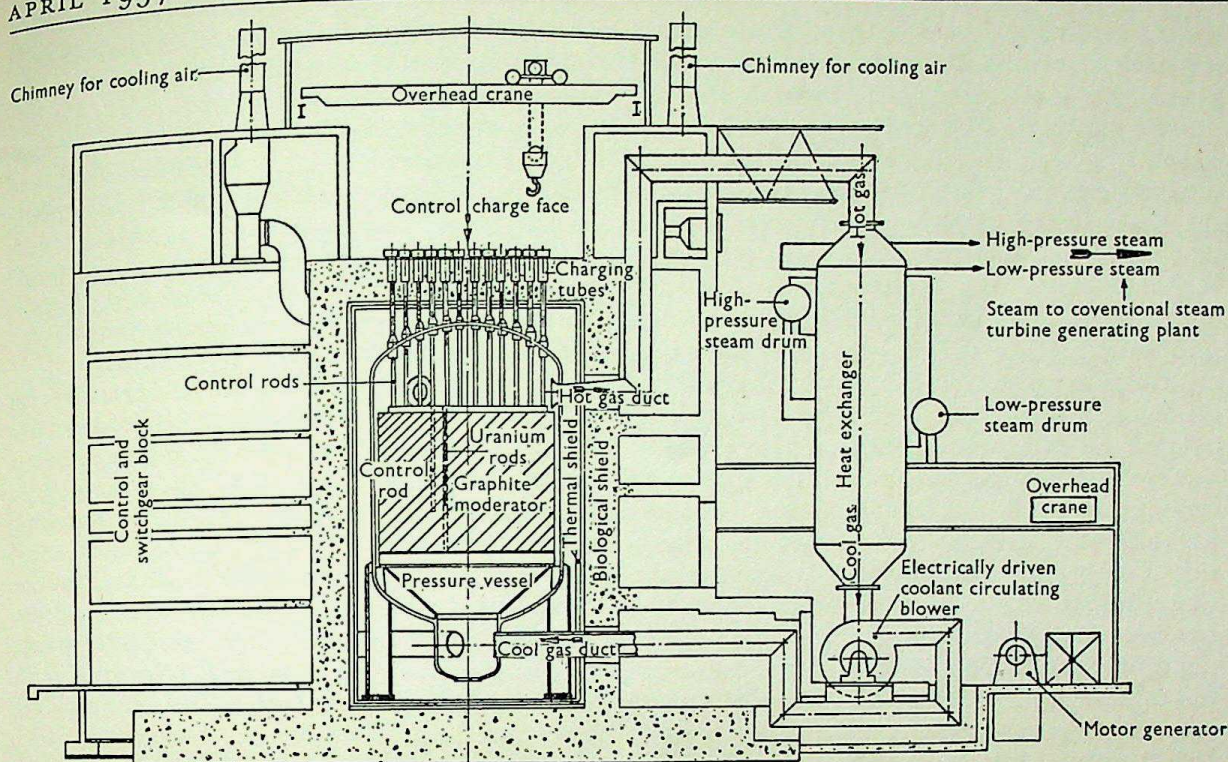


FIGURE 2 - Diagram of the Calder Hall reactor.

by four electrically driven blowers. It leaves the reactor at a temperature of 336°C and is passed over tubes whose heat-transfer surfaces have been increased by studs, resistance-welded on to them, giving up its heat through this transfer surface to water circulated within the tubes. Steam is raised at pressures of 200 lb per square inch and 53 lb per square inch, and is used in a dual-pressure feed in a conventional type of turbine to generate electrical power.

The Calder Hall type of reactor has the advantages that it is inherently stable; that its operation involves no greater risks than those that are normally associated with the operation of most conventional chemical plants; that it uses as its fuel natural uranium, which is widely available; and that its construction demands only materials and techniques which are well established. The reactors of this type which are at present being designed for use by the Electricity Authorities in Britain are able to generate power at a cost per unit approximately equal to the cost of power generated in a modern conventional power plant. The graphite-moderated gas-cooled reactor is the only system for which these claims can at present be made.

The system is obviously capable of very considerable improvement, and such improvements will be made in new designs as operating experience becomes greater and as research paves the way.

Improvements in welding and in industrial radiography will enable pressure shells of greater thickness to be fabricated. This will give the designer the choice between increasing the diameter of the reacting core, and thus pushing up the output of the system with consequent reduction in capital cost per unit of power, or alternatively of increasing the pressure of the circulating gas, and so achieving lower power absorption in the gas circulators, smaller temperature differences between the fuel elements and the gas stream, or higher ratings of the fuel elements.

Research on the metallurgy of uranium, uranium alloys, and canning materials, and on the stability of graphite, will enable higher temperatures to be achieved with better thermal efficiencies in the steam cycle. It is possible, too, that the difficulties of using hydrogen as a coolant will be overcome. These difficulties lie in the main in the probable hydrogen embrittlement of the steel parts of the pressurized gas system and in the reactivity of hydrogen with the uranium of the fuel elements. If these difficulties can be overcome, the use of hydrogen will lead to considerably higher ratings, with very much smaller power consumption in the circulating system.

With these improvements, it is probable that

under the conditions which exist in Britain and in some overseas countries the graphite-moderated gas-cooled reactor will be pre-eminently the best type for the large land-based power station for the next fifteen years and that it will continue to be installed for many years after that. The history of the development of all types of prime movers shows that in every type the weight per horse-power decreases with the passage of time, and nuclear power plants will certainly follow this classical pattern. The weight per horse-power of a nuclear power plant can fall only as the rating of the fuel elements is increased. It has already been pointed out that such increases of rating will be achieved in the graphite-moderated gas-cooled reactor, but liquid coolants are always physically capable of giving better heat-transfer characteristics than gaseous ones. Beyond a certain point, when further improvement of the gas-cooled system becomes slow and the present difficulties arising from the use of liquid coolants are overcome, the liquid-cooled reactor will gradually replace reactors of the gas-cooled type for many purposes. It is therefore essential that a well conceived programme for the development of nuclear power should direct attention to the design of reactors which are capable of these higher ratings.

HIGH-RATING REACTORS

Besides the fact that the history of prime movers points in this direction, there is an additional factor which points to the need for development in this way. Reactors using natural uranium as a fuel and producing electricity as their primary product, produce plutonium as a by-product. This plutonium, which can be extracted from the irradiated fuel elements by chemical processes that are now well established, is available as a nuclear fuel. It is a fissile material: it is inconceivable that unlimited quantities will be required for defence purposes, and it will therefore be available for use in the industrial programme. Many difficulties lie in the way of using plutonium as a fuel, but where such a material and the theoretical possibility of its use exist, methods of solving the difficulties will unquestionably be found. When extracted from the irradiated fuel elements, the plutonium will be available as a pure fissile material. To dilute such a pure fissile material down to the point where it could be used in a reactor of low rating would appear to be unsound from both a theoretical and a practical point of view. In order to get the best returns from such a material it ought to be used in a reactor which is capable of

very high ratings, so that large amounts of heat can be extracted from each kilogram of the valuable undiluted fuel which is employed.

It is therefore necessary to select some other types of reactor or reactors which are capable of being worked at high ratings, and to include these in the British development programme. This choice is by no means as easy as the choice which had to be made of a reactor for the first stages of the programme, when the graphite-moderated gas-cooled system almost selected itself.

For use in large land-based reactors we must still accept the fact that beryllium is not available in sufficient quantities, and so we must rule out its use as a moderator. The use of heavy water has in the past appeared unattractive because of its high cost. On the other hand, it must be remembered that the Canadian research team has always been disposed to favour the use of heavy water reactors, and they are at present engaged in designing such a reactor for installation on land belonging to the Ontario Hydro Electric Power Commission, about ten miles from Chalk River. The system which they propose uses heavy water as both moderator and coolant, the heat being transferred from the coolant circuit to a secondary light water cooling circuit from which steam is generated for use in the turbines. The system has all the metallurgical difficulties inherent in the use of very pure water at high temperatures and pressures, and one wonders whether under these conditions it would be possible to operate without loss of heavy water from the system. The Canadians, however, have great experience of using heavy water in reactor systems and appear to be confident on this point. The possibility of obtaining heavy water at far lower prices than were formerly assumed to be reasonable is in favour of their scheme. Figure 3 shows the schematic arrangement of the proposed reactor.

Nuclear physical stability of the core can be achieved either in a heavy water or a light water system if the moderator and the coolant are identical. In our consideration of the problem we felt that it would be preferable to use light water and to compensate for its poorer neutron economy by the use of enriched fuel elements. In a future system, this enrichment might be obtained by the use of by-product plutonium from the stage 1 reactors. The choice between these two systems is largely one of deciding whether it is better to invest in an expensive moderator and coolant, or to use a cheap moderator and coolant and invest in an expensive fuel.

Several studies have been carried out on the

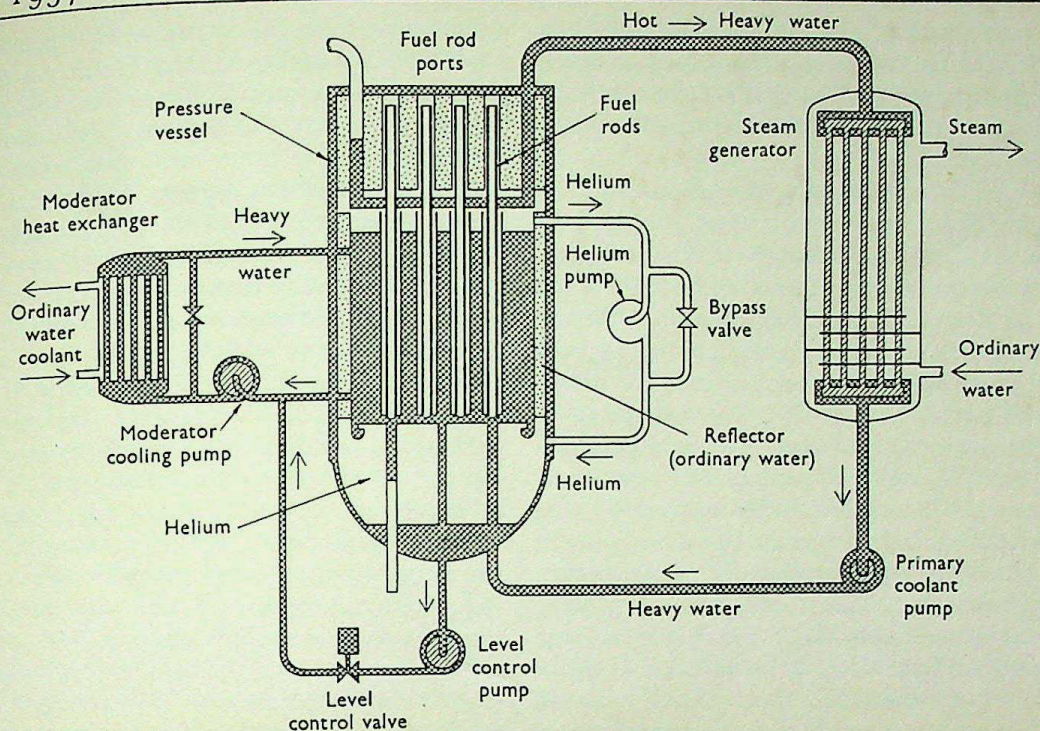


FIGURE 3 - Proposed design for a reactor using heavy water as moderator and coolant. (By courtesy of Atomic Energy of Canada Limited.)

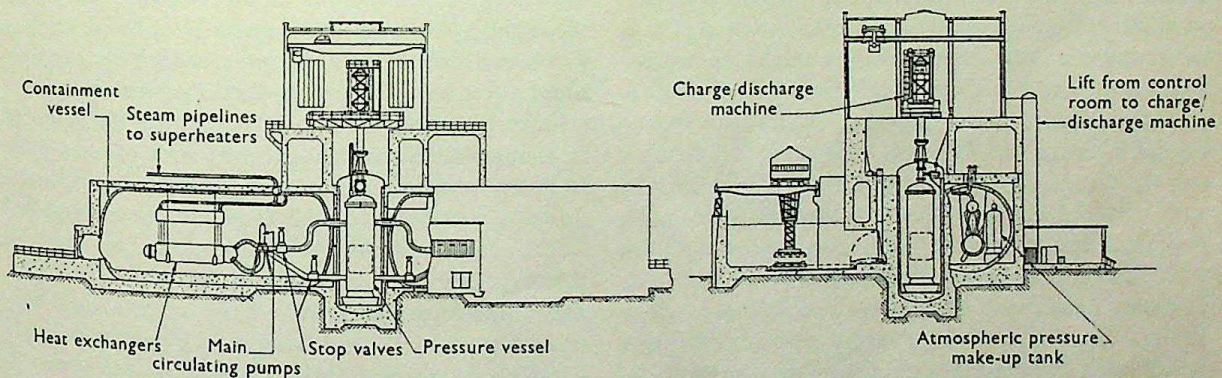


FIGURE 4 - Tentative scheme for a reactor moderated and cooled by light water.

feasibility of reactors both moderated and cooled by light water, and a possible scheme evolved in the course of these is shown in figure 4. It appears that if such a reactor could be successfully built and operated, the cost of generating electricity from it would be rather higher than the cost expected from the graphite-moderated gas-cooled reactors at present being designed. This, however, should not be too great a discouragement, because the system is capable of development to very high ratings, and costs must always be expected to fall as design experience is obtained. The disadvantage of the scheme shown, and of all other schemes which can at present be envisaged, is

that it appears to be necessary to put the moderator under a pressure of about 1500 lb per square inch. This demands the use of a thick pressure vessel, and practical problems in the fabrication of such vessels place a limit on the size of the reactor that can be built. It does not appear that any amount of future development work can remove this limitation. It is possible that the difficulty may be alleviated by evolving a system in which the water of the moderator is allowed to boil, and this possibility is being studied. There remains, however, the disadvantage that the water used in the moderator must be extremely pure and that under the conditions of temperature

and pressure that have to be achieved, such pure water is extremely corrosive. The attack of water on metallic uranium is such that it is hardly suitable for water reactors, and uranium dioxide is generally used.

In spite of these difficulties, the water-moderated, water-cooled reactor is a type favoured in America. It is probable that American development work moved in this direction because at an early stage they expended considerable effort to evolve a reactor system suitable for use in submarines. Such an application demanded a reactor capable of higher ratings than those that can at present be achieved by gas cooling, and the difficulty of working under the completely dry conditions that must be achieved when sodium is being used probably weighed against the use of this as a coolant. Their water-moderated, water-cooled submarine reactor has been in operation for some time, and from it they have developed a large land-based reactor which is being built at Shippingport. Their published figures for the cost of power from this reactor do not at present appear as promising as those for the gas-cooled reactors.

The use of liquid metals as coolants with either water or heavy water as a moderator is very unattractive, because it would be extremely difficult to design a system in which one could guarantee freedom from a failure which brought the water and the liquid metal together, with consequent chemical reaction. We are, therefore, left to consider systems in which graphite is used as the moderator and either water or liquid metal as the coolant. Such a system, with a water coolant, has been built in Russia. The reactor, of which the Russians disclosed details at the Geneva Conference on Peaceful Uses of Atomic Energy, is a small prototype, with a total thermal capacity of 30 MW, in which the fuel elements are arranged vertically in stainless steel tubes which run through the graphite moderator. Whether nuclear stability has been achieved by proportioning the thickness of the water annulus is not clear, but apart from this, the reactor appears to be conservatively designed, and, as is reasonable in a prototype, economy seems to have been made subservient to reliability. An inherent disadvantage of this design is that the stainless steel pressure tubes within the core must be of appreciable thickness, and so impair the neutron economy. It seems a little questionable whether the design can be developed in such a way as to enable power to be produced on a large scale at costs which would be competitive under British conditions.

There remains the graphite-moderated reactor cooled by liquid metal, and for this, sodium appears to be the most suitable coolant. This reactor appears to have the objection of inherent nuclear instability, but it must be remembered that the condition in which sodium is vaporized in the cooling passages within the core ought not to occur. It follows, therefore, that if the mechanical construction of the reactor is such that in the event of failure the sodium circuit will empty itself into the core, nuclear stability ought to be ensured. Like all the other systems for highly rated reactors that we have considered, with the exception of that which uses heavy water, this system will demand the use of enriched fuels, but it has the advantage that because of the high boiling point of sodium the cooling system does not need to be put under an appreciable pressure. The engineering problems connected with the use of liquid sodium are now well understood.

FAST REACTORS

Hitherto our consideration has been confined to thermal reactors, i.e. reactors in which it is necessary to arrange a lattice of fuel within a moderator in order to maintain our chain reaction. If instead of using a fuel which is heavily diluted with a fertile material (i.e. a material which by neutron absorption forms another fissile material) we use a fuel which consists almost entirely of fissile material, the moderator clearly becomes unnecessary. In such a reactor the neutrons are not slowed down, and reactors of this type are therefore called fast reactors. There are two main advantages in this type of reactor. Firstly, even the best and purest moderators give rise to some useless absorption of neutrons. Secondly, while in any thermal reactor system most of the neutrons that are captured by the fissile material cause fission to take place, some are captured without causing fission and cause the loss not only of the neutron but of a further atom of fissile material. In a fast reactor nearly every neutron striking a fissile atom causes fission to take place. Fast reactors are thus potentially capable of very much better neutron economy than any thermal reactor. With this good neutron economy, it is possible to achieve an arrangement in which the number of new fissile atoms produced within a fertile material that can be incorporated in the assembly is greater than the number of fissile atoms that are destroyed. In fact, while releasing heat which could be used in generating electrical power, we breed additional fuel. For this reason reactors of this type are

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frequently referred to as breeder reactors, and this characteristic makes it extremely desirable to develop the fast fission reactor for use in the industrial programme.

There is an additional reason why development of the fast breeder reactor is necessary. In discussing the primary thermal reactors in which natural uranium is used as a fuel, it has been pointed out that they produce plutonium as a by-product, and that in order to achieve a balanced nuclear power industry it is necessary to devise reactors in which this by-product plutonium can be used as a fuel. To some extent this can be done by burning the plutonium in thermal reactors, which for economy must have sufficiently high ratings. But when plutonium is subjected to neutron irradiation, some of the atoms absorb neutrons to form higher isotopes which have even greater neutron absorption cross-sections. For this reason the use of plutonium in a thermal reactor cannot give rise to high neutron economies. The absorption cross-section of plutonium and its isotopes is much lower for fast neutrons than for thermal neutrons, and plutonium is therefore much better as a fast reactor fuel than it is as a thermal reactor fuel.

At present the United Kingdom Atomic Energy Authority is constructing a prototype fast reactor at Dounreay, in the north of Scotland. It is interesting to note that because the ultimate desirability of this system and the immense problems involved in developing it were realized at an early stage, the Dounreay project was put in hand before construction was started on the Calder Hall reactors.

The arrangement of the Dounreay fast reactor is shown in figure 5. Because sufficient quantities of plutonium were not available for research purposes, the reactor will use highly enriched U^{235} as its fuel. It will, however, be possible to insert some plutonium fuel elements so that information on their metallurgical and nuclear physical behaviour can be obtained simultaneously with the other scientific and technological development work that will be carried out on the prototype. The fuel elements, in the form of tubes made of enriched uranium, each of which is enclosed in a can of very special construction, are arranged in a cylinder about 2 ft in diameter and 2 ft long. From this cylinder a heat release of 60 MW must be achieved: this necessitates heat-transfer rates of up to $\frac{2}{3}$ kW per square centimetre of fuel element. It is obvious that in order to achieve such a high heat-transfer rate it is desirable to use a liquid metal coolant. In order to minimize the ancillary

problems in the development of the reactor it was decided to use sodium-potassium alloy having a melting point sufficiently low to ensure that the metal will not become solid at the temperatures to which the reactor will normally fall when it is shut down. The small reacting core is surrounded by rods of fertile material in which the excess neutrons will be absorbed and the secondary fuel bred. Initially uranium will be used as the fertile material, but one of the advantages of the fast reactor is that it enables us to gain a point of access to the thorium cycle. When subjected to neutron bombardment, thorium forms, by neutron absorption and subsequent decay, an isotope of uranium (U^{233}) which is fissile. This isotope has advantages as a secondary fuel both because its neutron emission characteristics in thermal reactors are better than those of either plutonium or U^{235} and because the metallurgical properties of U^{233} are far more favourable than those of plutonium. Thorium can, of course, be used as a fertile material in any reactor where spare neutrons are available for absorption, and it is possible to introduce it into thermal reactors that are so arranged as to have excess neutrons.

The fast reactor, and indeed all reactors having very high ratings, gives rise to safety problems which we have not had to consider in connection with the thermal reactors that have been discussed. The heat output of the reactor core is extremely high, and its mass and heat capacity are low. If, therefore, there were a complete interruption in the flow of coolant, it might happen that the heat emission from the fuel would melt the reactor core. At Dounreay the primary safeguard against this is a multiplicity of cooling circuits, each with its own pump and divided into separate groups with distinct sources of power supply. A catastrophe is therefore almost inconceivable, but should it happen there is an even more remote possibility, that the sodium-potassium alloy might ignite, even though the liquid metal is buffered with an inactive gas, and by volatilizing the fission products present in the fuel elements would disperse active material over the district. In order to guard against this, the whole assembly has been encased in a metal sphere, the diameter of which is 135 ft and which has been designed to be of sufficient strength to withstand the calculated pressure of the products of combustion if this most unlikely incident should occur.

A fast reactor presents problems of tremendous difficulty, but by far the most complex and difficult lie within the fuel elements themselves. Although

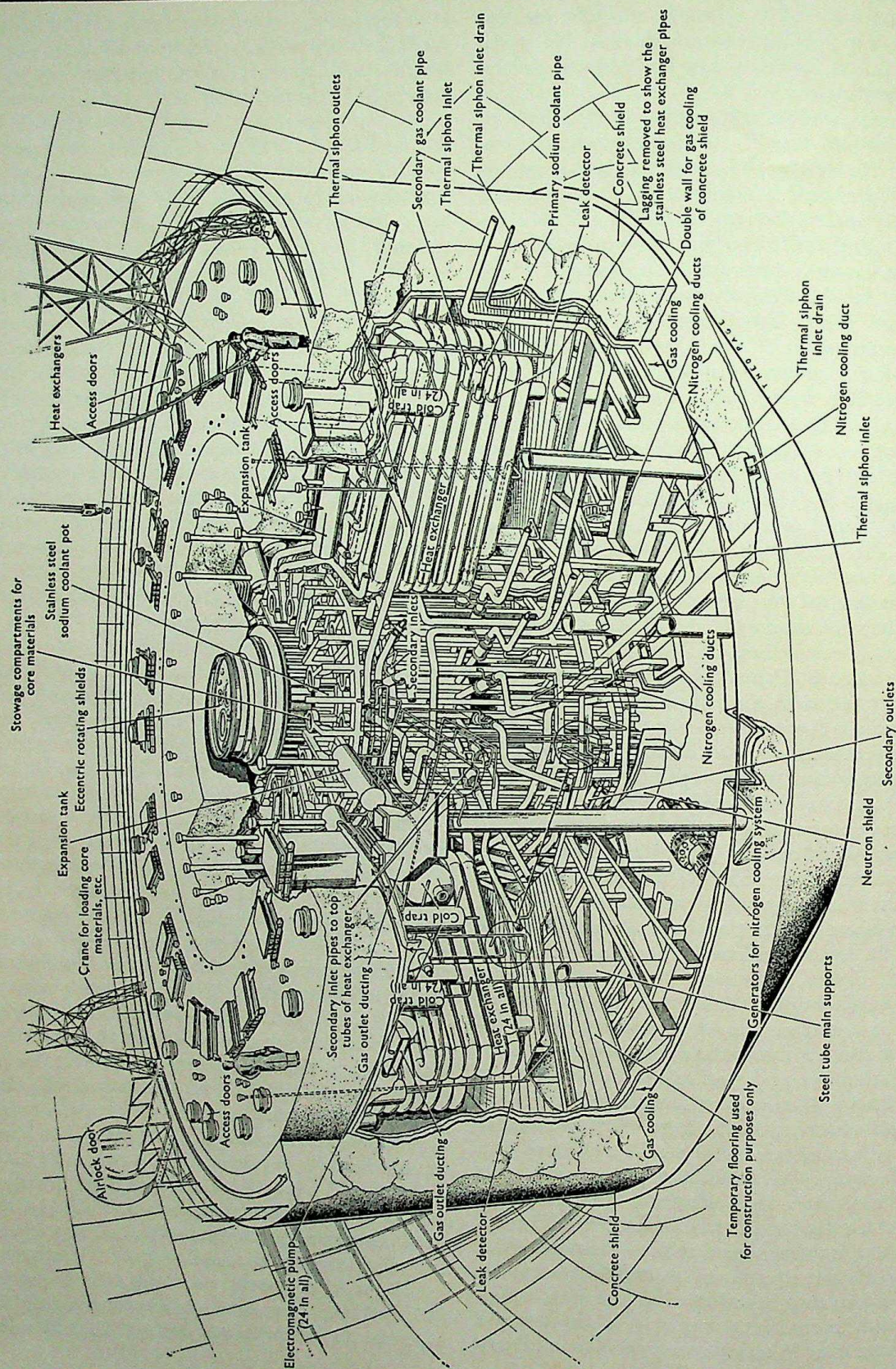


FIGURE 5 — General arrangement of the Dounreay fast reactor. (By courtesy of Nuclear Power.)

heat flows of $\frac{2}{3}$ kW per square centimetre from a surface are not frequently demanded in industrial practice, they can be achieved. But in a reactor, the heat which is thus being conveyed away from the surface is generated by fission within the mass of metal in the fuel elements, and uranium has not a high thermal conductivity. The temperature gradients within the fuel element are therefore considerable. Uranium has two allotropic change-points, and the change of volume at the upper of these two is so considerable that to pass through it would so alter the nuclear physical characteristics of the core as to make stability of control questionable. The creep rates of uranium at elevated temperatures are high, and it is therefore necessary to give the fuel some support from the can. But uranium is also a reactive metal, and the choice of canning materials which will give this support, which have suitable low neutron cross-sections, which have a sufficiently high thermal conductivity, and which are not chemically reactive with uranium at the temperatures which will be experienced in the reactor, is a difficult problem.

Within the life of the fuel elements inside the core quite a high proportion of its atoms will be destroyed by fission; in order to make a fast reactor operate economically it is probable that burn-up rates of at least 1 per cent must be achieved before removal of the element from the reactor for re-processing. Some of the fission products are gaseous and are capable of building up pressures within the metal, while the formation of the others necessarily tends to break down the initial structure and weaken the material. There is therefore a serious danger that the metal of the fuel element may itself disintegrate.

The prototype reactor, which will be in operation at Dounreay in 1958, is designed to provide facilities for the investigation of these and other problems. It will not provide a basis on which fast breeder reactors can be designed for use in industry. Before this can be done, the Dounreay prototype will have to be followed by a pilot reactor, and it is probable that supply authorities will not be in a position to place orders for commercial types until the mid-1960's.

Fuel element problems are by no means confined to fast reactors; indeed, it is probably true to say that for any type of reactor that can be built, the performance will for many years to come be limited by the fuel element. Moreover, the fabrication and canning of fuel elements, and their subsequent treatment after irradiation, are expensive and complicated processes. It is with a view to eliminating these problems of the solid

fuel element that thought has been given to homogeneous systems, in which the fuel is circulated in solution or in suspension through the reacting core. Basically the simplest of these systems is probably the one in which the liquid fuel consists of a solution of uranium sulphate in heavy water, and a small reactor of this type has been built in America. Although it has great attractions, even more unsolved problems are involved than with the fast reactor. In order to be economical and practical, the system has to work under high pressures and temperatures, so that all the problems of corrosion by water of materials of construction are likely to arise. In addition, there is both chemical and nuclear breakdown of the fuel, which introduces impurities into the system, making the corrosion problem even more difficult. Some of the fission products are gaseous, and these must be removed. Figure 6 shows a schematic flow diagram. There are alternative homogeneous systems in which the fissile material is used as a molten salt or in which it is in solution or suspension in liquid metals, but none of these systems removes the acute difficulties that have to be solved.

Moreover, the homogeneous systems must inherently demand far greater skill on the part of the operators. A plant in which reactors of the Calder Hall type are installed is no more difficult to operate, from a works management point of view, than a conventional power plant; in fact, in some ways it offers fewer problems. Fabrication of the fuel elements will be carried out in factories specializing in these processes, and the completed fuel elements will be transported to the power station site for insertion into the reactor. The highly specialized chemical treatment of the irradiated fuel elements for a national industrial programme for nuclear power production will be done in no more than two or three chemical factories, so located that any radioactive effluents can safely be discharged into tidal water. They will be staffed with men who are trained as chemists and chemical engineers, and are experienced in the running of such plants. By contrast, in order to make a homogeneous system work satisfactorily, it is almost certain that there must be continuous chemical processing of the fuel; thus each power plant will contain its own chemical plant, carrying out a highly specialized process and giving rise to a certain amount of active effluent. While there can be considerable freedom in choice of sites for reactors using solid fuel elements, it thus appears that the selection of sites for homogeneous reactors will be more difficult

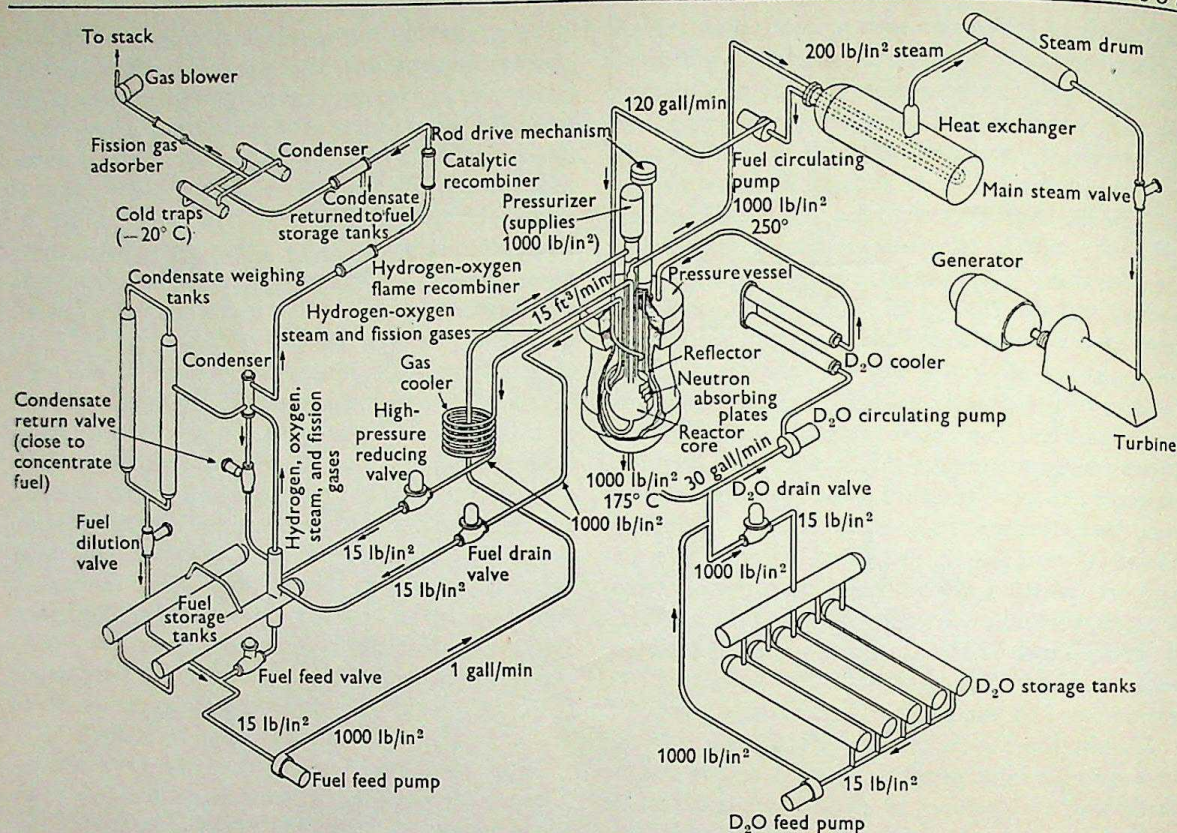


FIGURE 6 - Schematic flow diagram for a homogeneous reactor.

and that it might be found that they can be placed only on coastal sites, from which effluents can be discharged into the sea at an appreciable distance off-shore. Each station will also require a staff competent to control a complex chemical process.

Although among some experts there is great enthusiasm for the homogeneous system, and although the advantages of ridding oneself of the problems of the solid fuel elements are very attractive, it seems possible that not only the technological problems of design and construction, but the problems of subsequent operation will postpone into a fairly distant future the date when they will become widely used.

All the reactors so far discussed in this article have been considered from the point of view of their use in large land-based stations, and it is towards the solution of these problems that most British work has been directed in the past. The primary reason for this lies in the fact that the most urgent need in Britain is for reactors which will help to relieve the demands for conventional fuels, which are outrunning supplies. It is in the field of the large land-based reactor that atomic

energy can make the greatest contribution in this respect. It would, however, be wrong to forget that even though both the national need and the market are smaller, there is also a demand for reactors which, instead of producing, say, 150 MW of electrical power, are capable of producing 20-30 MW of power. These are the reactors for which there is the greatest need in overseas countries which have not yet achieved a high state of industrial development; reactors of these and smaller sizes would also find uses on mobile platforms such as steamships.

It is almost inevitable that the cost of power produced in such small reactors should be higher than the cost of power produced in large land-based reactors. On the other hand, in certain specialist applications such higher costs may be tolerable. Almost certainly, natural uranium can be used in such small reactors only if heavy water is used as a moderator; if graphite, beryllium, or light water are used for moderation, the use of slightly enriched fuel would seem to be inevitable. We have already seen that for the highly specialized application of submarine propulsion the Americans have developed a reactor both moderated

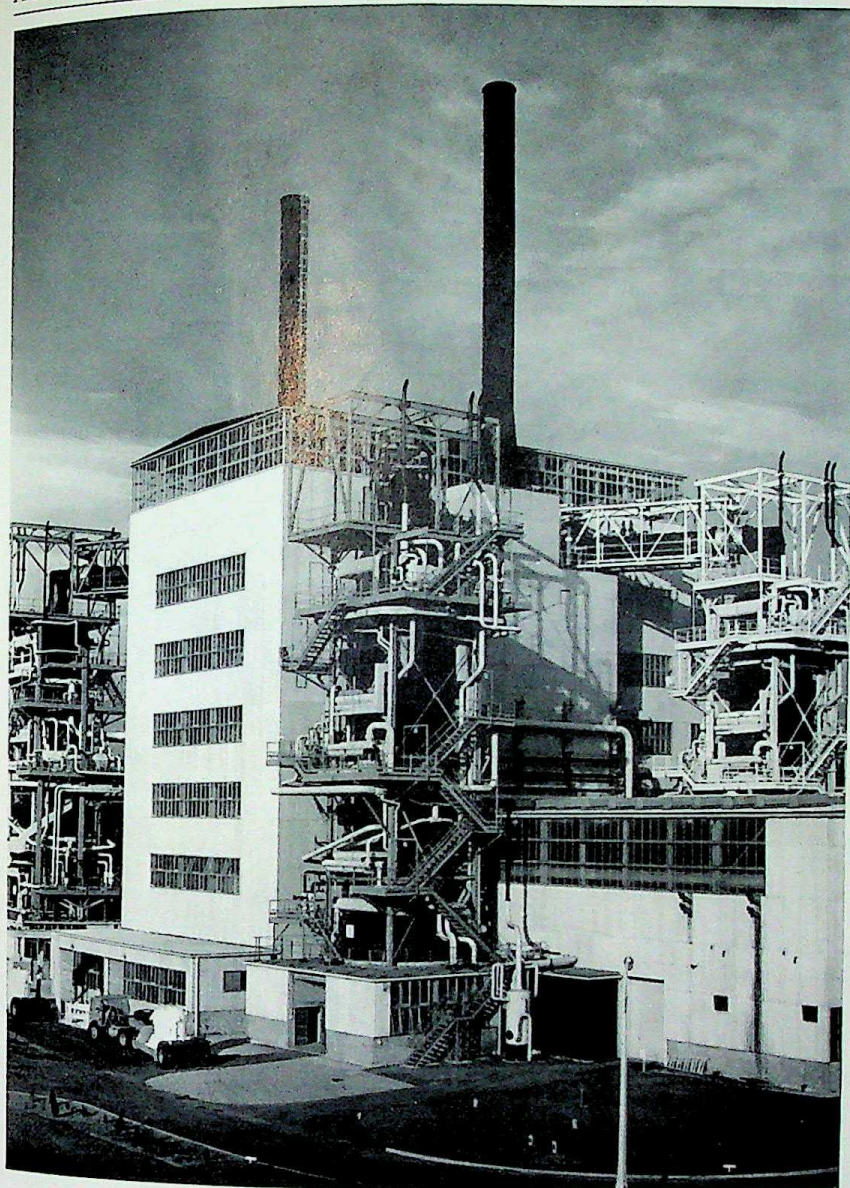


FIGURE 7 — General view of a Calder Hall reactor.

and cooled by light water, and British work on a similar project is at present proceeding. There can be no doubt that the Americans have achieved considerable success in this abnormal application. Whether the system can be so cheapened and simplified as to make it attractive, for instance on merchant vessels and for the small land-based installations, remains at present a matter for speculation.

A system which has hitherto not been mentioned, and which might also show suitability in this field, is one in which heavy water is used as a moderator and a gaseous coolant is used; the Russians have done some work on such a system.

The demand for compact and lightweight nuclear reactors for special applications will lead to the design of plants in which the conditions are met only by the use of special materials and of which, for that reason, the capital costs are high. These special applications, however, will enable techniques to be developed which reduce the difficulties and costs of construction and so bring prices down to the level at which installation can be justified in more normal cases. Meanwhile new special cases will arise demanding new exotic and expensive solutions, and these in their turn will in time become normal practice.

NUCLEAR FUSION

Beyond all the possibilities which have been discussed in this paper, lies that of the nuclear fusion process. In all the power plants that have been discussed, heat which is converted into electrical or mechanical energy arises from the fission of atoms at the end of the periodic table. It is, however, possible to release heat by the fusion of light elements. In order to do this, the atoms to be combined must be accelerated to velocities corresponding to tem-

peratures above $1\,000\,000^{\circ}\text{C}$. At present we have only the most elementary ideas of how this might be accomplished on the industrial scale, and it will be many years before we can supply information to the engineers which would enable them to build the first infantile prototype of such a system. Even with the possibility of breeding, there must be some limit to the amount of fissile material which is available as an industrial fuel. When the nuclear fusion process can be harnessed to industrial power production, this limit will be removed and it would not be unreasonable to predict that power plants using the nuclear fusion principle will be in industrial use early in the twenty-first century.

Spore liberation in higher fungi

C. T. INGOLD

The late Professor A. H. R. Buller showed mycologists that the way to a proper understanding of the wonderful range of form in fungi was to study them as living mechanisms involved in the production and liberation of spores. This article reviews some interesting recent work in this field with special reference to a basidiomycete and an ascomycete, and shows how highly the larger fungi are organized in respect of the liberation of spores.

In higher fungi (Basidiomycetes and Ascomycetes) the conspicuous part, the fruit-body, is essentially an apparatus concerned with the production and liberation of spores. The feeding mycelium is normally hidden as branched hyphae in the nutrient substratum. In general the spores of higher fungi are dispersed by wind, although there are conspicuous exceptions, such as the stink-horn (*Phallus impudicus*) with spores spread by flies; the subterranean truffles (*Tuber* spp.) with spores dispersed by rodents; and the beautiful little dung fungi (species of *Ascobolus*, *Sordaria*, and *Coprinus*) with spores normally disseminated through the alimentary canal of herbivorous animals [1]. In dispersal as a whole there are commonly three episodes: spore liberation, the actual dispersion through the air, and the coming to rest of the spores on the substratum. Here we are concerned with the first episode.

Once the spores get into the turbulent air, the study of their dispersal is essentially a meteorological problem, since, because of their small size (most being smaller than the water droplets in mist) their movement is determined by the behaviour of the air mass in which they become incorporated. It should be emphasized that the first step in dispersal is not merely the freeing of the spores from immediate contact with the parent body, but also the launching of the spores into the turbulent layer of the air so that their subsequent dispersal is assisted.

By way of illustrating the problems involved in spore liberation two fungi common in Britain, one a basidiomycete (*Ganoderma applanatum*) and the other an ascomycete (*Daldinia concentrica*) will be considered here.

Ganoderma belongs to the Hymenomycetes, the largest group of Basidiomycetes, characterized by having its spore-producing surfaces (hymenia) exposed at maturity. In most fleshy toadstools (Agaricaceae) the hymenium covers the surface of

vertical lamellae (gills), but in Polyporaceae, to which *Ganoderma* belongs, the hymenium lines vertical pores.

The spore-producing unit of the hymenium is the basidium, a single cell with a characteristic development, which produces four basidiospores externally on fine sterigmata. These microscopic basidia are elongated at right angles to the hymenial surface, and are thus normally horizontal. Each spore is poised asymmetrically at the end of its sterigma, and very near to its point of attachment is a small projection (hilum). Just before the discharge of the spore a drop of fluid suddenly appears at the hilum, grows to a certain definite size, and then the spore is shot away, carrying the drop with it. Fungal spores discharged in this manner have been termed 'ballistospores'. Shortly after the discharge of one spore another is shot away, and so on until all four have gone. Then the basidium slowly collapses. In *Ganoderma* the distance of discharge is about 0.005 cm¹. In other Hymenomycetes it tends to be greater, but seldom exceeds 0.02 cm.

The mechanism of violent spore discharge in Hymenomycetes is not clearly understood. A. H. R. Buller [2] considered that the drop originated at a small distance from the sterigma and was essentially exuded by the spore. This is clearly shown in his figure of discharge in the gelatinous fungus *Calocera* (figure 6). Others consider that the drop exudes at the junction of the spore with the sterigma. D. Müller [3] has made a cinematographic study of ballistospore discharge in the mirror-yeast *Sporobolomyces*. He claims that sometimes the drop of fluid is discharged, leaving the spore behind on its sterigma. His picture of discharge is that rupture of the turgid sterigma occurs at its junction with the spore, and that a drop of fluid is expelled which ordinarily carries the spore with it. Another theory, strongly supported by

¹ Unpublished determination by the author.

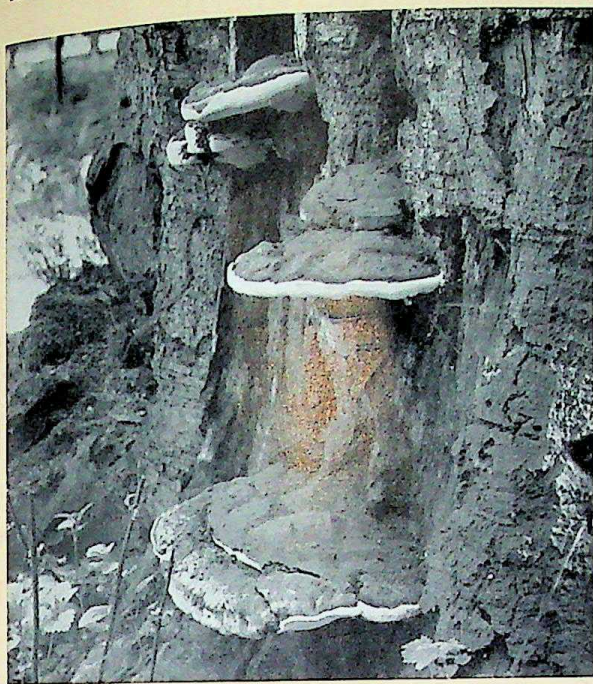


FIGURE 1 - *Ganoderma applanatum*. Fruit-bodies growing on beech. Photograph by Dr Somerville Hastings.

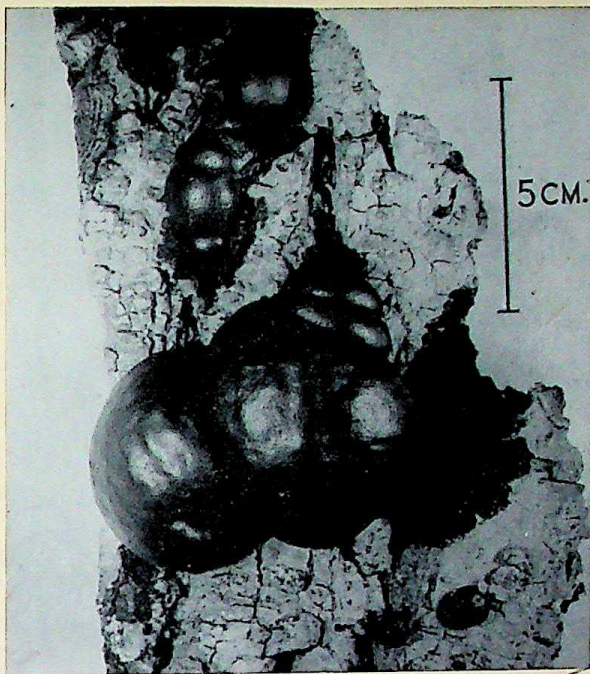


FIGURE 2 - *Daldinia concentrica*. Stromata on ash.



FIGURE 3 - *Daldinia concentrica*. Black spore deposit formed overnight around a thick slice of stroma laid horizontally on a glass plate.

FIGURE 4 (right) - Apparatus for studying spore discharge in *Daldinia*. The stroma is held in a clamp and spores are shot through a vertical slit in a metal screen, being sticky, they adhere to the white paper on the drum, which makes one rotation in a week.

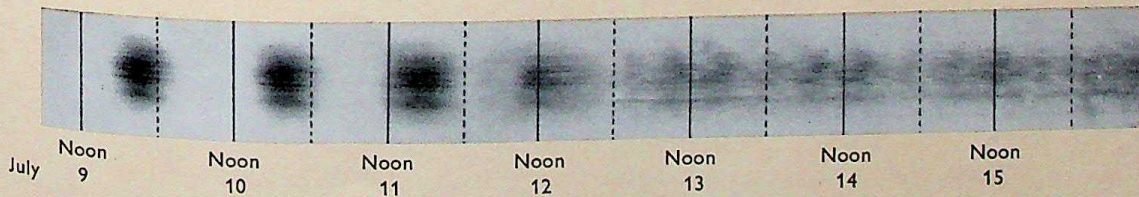
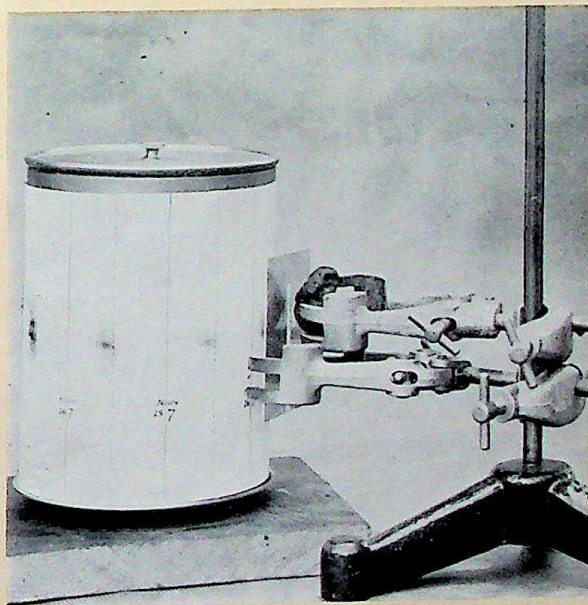


FIGURE 5 - Spore trace obtained using apparatus shown in figure 4. Temperature and humidity were kept fairly constant (temp. 20.5-23° C.; rel. hum. 92-94 per cent) and the fungus was in continuous darkness. The nocturnal rhythm of spore discharge has, however, continued for some days. The interrupted vertical lines show the positions of midnight and the uninterrupted lines positions of noon.

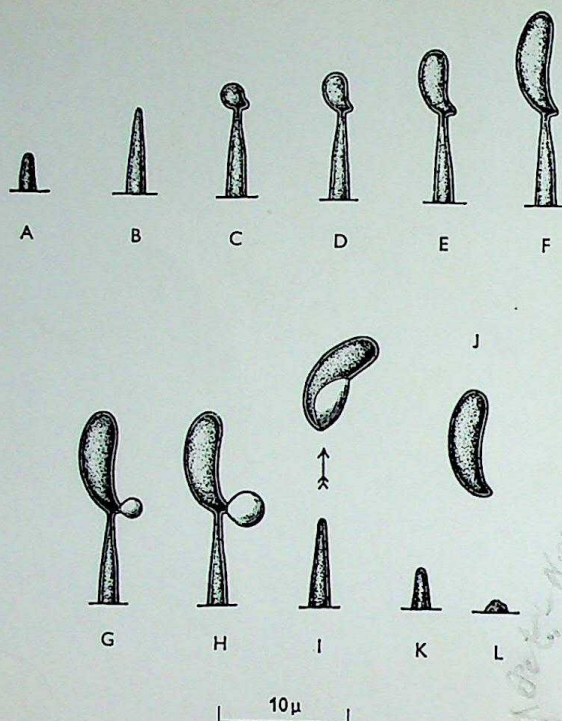


FIGURE 6—*Calocera cornea*. A–L, stages in the development of the basidiospore at the end of the sterigma and subsequent spore discharge. After Buller [2].

the observation of A. E. Prince [4], is that there is a cross-wall at the junction of the spore with its sterigma. Both spore and basidium are turgid cells, and at this junction strains are set up, the tip of the sterigma and the spore both tending to round off. These strains are released suddenly, with the result that the spore springs off from its sterigma. This type of discharge is well known in certain lower fungi belonging to the genus *Entomophthora*. However, if this is the true mechanism it does not bring the exuded drop into the picture. It has also been suggested [5] that the surface energy of the drop might be mobilized for spore discharge, but the evidence in support of this view is very slight. It must be admitted that the problem of spore discharge from the basidium is not yet solved.

Ganoderma applanatum (figure 7) is one of the very few fungi with a perennial fruit-body. A single specimen may remain active for five years or more, adding an annual increment to the tube layer each summer. The fruit-body consists of a hard woody semicircular bracket, triangular in vertical section (figure 1), broadly and firmly attached to the tree, often beech, ash, or oak. The bracket may be half a metre or more across. The

pores or tubes occur on the under surface. In its growth each is positively geotropic. The tubes lined by hymenium are long (often several centimetres) and very narrow, with an internal diameter of only about 0.01 cm (figures 8–10). However, because of the accuracy of the geotropic growth of the pores and of the great rigidity of the bracket, the tubes originate and remain in a strictly vertical position. They increase in length during the late spring and summer, but rest during the cold seasons, to resume their growth in the spring. Active hymenium is produced not only in the extensions to the tubes made in the current season, but also in regions of the tubes which are two or three years old. The active hymenium, with ripe basidia, does not extend quite to the orifice of each tube but stops about half a millimetre short of it. In this region, including the growing free margin of the pore, the hymenium is not yet mature.

Each year, spore discharge starts in May and continues until September, and during this time the output is continuous. It has been calculated [2] that a large specimen liberates 20 million spores a minute continuously for the five or six months of its annual activity. An unusual feature of this fungus is that discharge goes on even during prolonged periods of drought [6]. *Ganoderma* is clearly a xerophyte: this xerophytism is probably partly due to the hard lacquered upper surface from which water loss is slow, and partly to the very narrow hymenial tubes, within which the air must remain nearly saturated. However, these features alone would not explain the xerophytism.

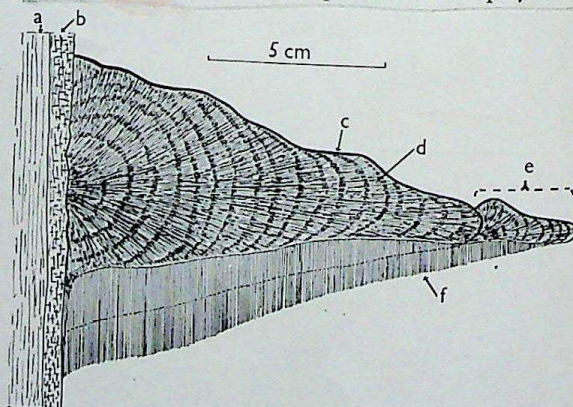


FIGURE 7—*Ganoderma applanatum*. Vertical section of a small fruit-body growing on ash. a, wood; b, bark of ash tree; c, upper 'crust' of fungus; d, zoned fibrous cap tissue formed in first year; e, additional cap tissue produced in the second year; f, hymenial tubes (the dotted line indicates the boundary between the tubes formed in the first year (above) and in the second (below)).

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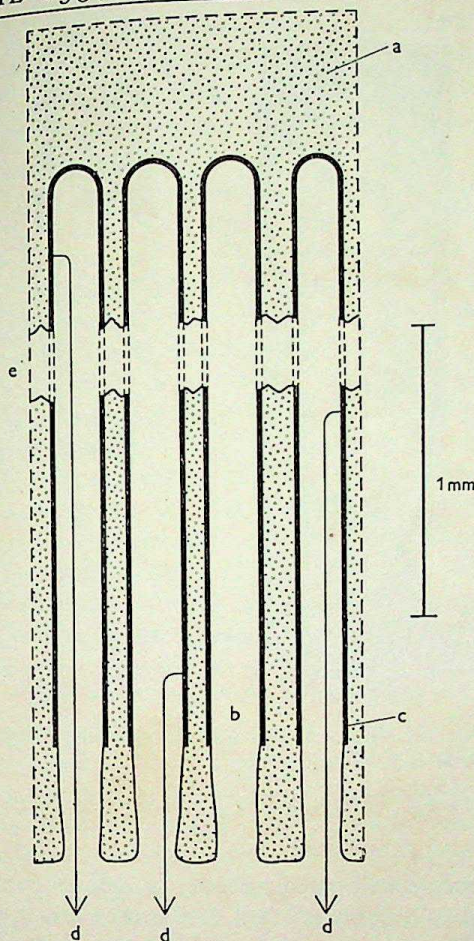


FIGURE 8 - *Ganoderma applanatum*. Diagram of longitudinal section of hymenial tubes. a, cap tissue; b, hymenial tube; c, active hymenium shown by thick black line; d, trajectory of a discharged spore; e, gap in the diagram corresponding to about 20 mm in the actual specimen or 760 mm at the scale of this figure.

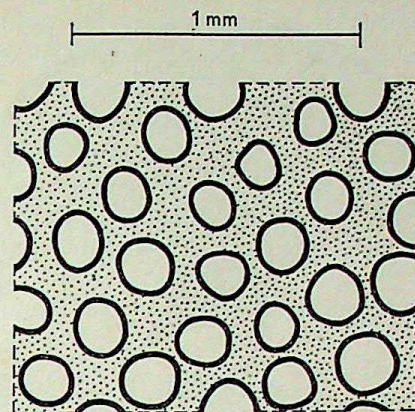


FIGURE 9 - *Ganoderma applanatum*. Transverse section of hymenial tubes. The thick black line around each pore is the hymenium.

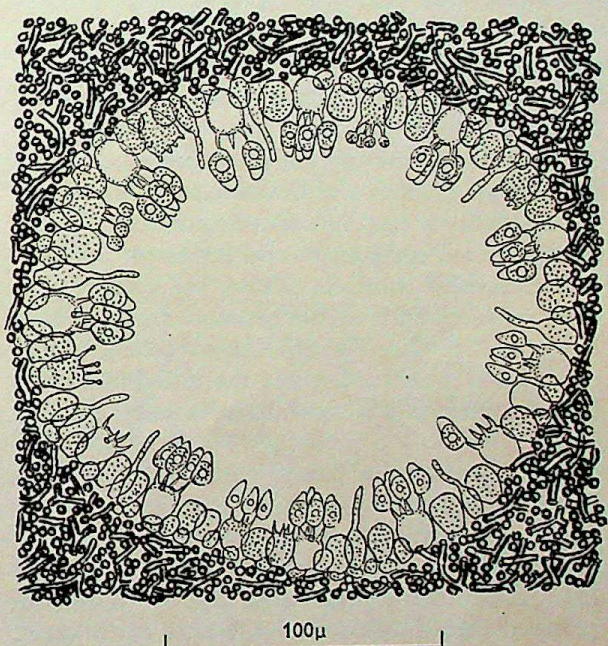


FIGURE 10 - *Ganoderma applanatum*. Drawing of a single hymenial tube seen in transverse section. The hymenium consists mainly of thin-walled basidia at various stages of development. The rest of the tissue is composed of intertwining thick-walled branched hyphae.

There must be substantial water conduction from the feeding mycelium in the tree trunk to make good loss by evaporation. It is worth observing in passing that lack of knowledge of how water and food are conducted is one of the greatest gaps in fungal physiology.

It has already been noted that the pores are only 0.01 cm wide and that the spores are shot to a distance of 0.005 cm, that is to say into the middle of the tube. They then fall in the still air within the tube and finally emerge below the bracket into turbulent air. It is to be noted that there is here no margin of safety. If the tubes were not exactly vertical this escape would be impossible. The spores are sticky, and if they were to touch the lining of the tube they would become permanently stuck, yet in sections such stranded spores are rarely seen. It seems possible that there

is some force keeping the spores in mid-stream during their fall down the hymenial tubes: perhaps an electrostatic repulsion is involved.

The story of spore liberation in toadstools and bracket fungi generally is essentially the same as in *Ganoderma applanatum*, but the special features of that fungus are its longevity, in contrast to the ephemeral nature of most toadstools; its xerophytism, in contrast to most Hymenomycetes, which are either incapable of withstanding drought or can endure it only by passing into a

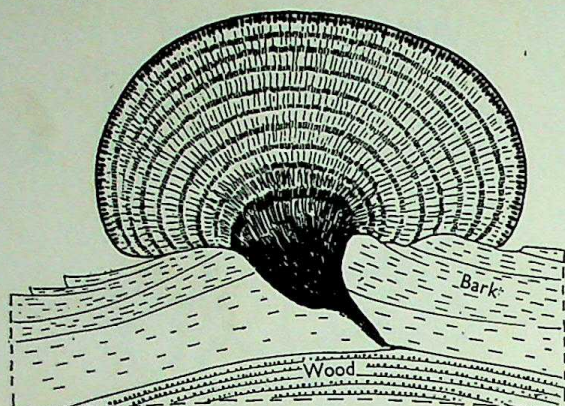


FIGURE 11 – *Daldinia concentrica*. Vertical section of a stroma on ash. The black dots within the surface are perithecia. ($\times 1.5$)

state of suspended activity; and its great rigidity, in contrast to the flimsy structure of so many fungi.

Our second example, an ascomycete belonging to the Pyrenomycetes, is *Daldinia concentrica* (figure 2), a common fungus appearing as hard black hemispherical cushions several centimetres in diameter on dead trunks and large branches of ash; very occasionally it occurs on other trees, such as beech and birch. The feeding mycelium in the dead wood is perennial, but the individual fruit-body or stroma remains alive for only a single season.

In vertical section (figure 11) it is seen that the stroma is zoned in a concentric fashion, and this feature gives the fungus its specific epithet. If a specimen is examined during its period of activity (May to September) it is found that very numerous perithecia are immersed in the hard outer crust. Each of these is flask-like, and opens to the outside by a narrow canal. Within, lining the walls of the perithecium, are numerous asci in various stages of development (figure 12). The ascus is the spore-producing unit of Ascomycetes (figure 13): it has a characteristic development and at maturity is a turgid living cell containing usually eight ascospores. In *Daldinia* the ripe spores are almost black. All round the asci, and completely filling the perithecium, is a mucilaginous slime. In spore discharge a single ascus elongates up the perithecial neck-canal and, when its tip reaches the outside, bursts, shooting its spores to a distance of 0.2–1.4 cm. As soon as one ascus has discharged, another elongates up the canal, and so the process goes on. Unlike the basidium, there is no mystery about the mechanism of discharge of the ascus. It

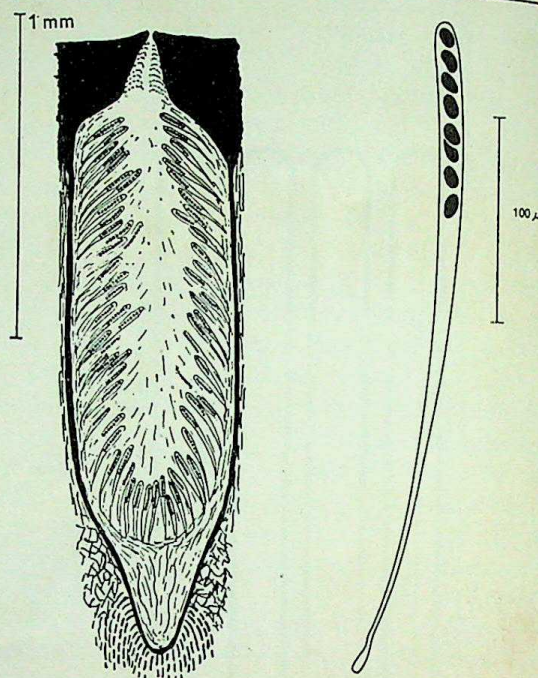


FIGURE 12 (left) – *Daldinia concentrica*. Single perithecium in vertical section.

FIGURE 13 (right) – *Daldinia concentrica*. Single ascus.

is a turgid cell which finally bursts at an apical region of weakness, and the spores are squirted into the air.

It is worth remarking that the ascus is a much more powerful spore gun than the basidium. The recorded distances of basidiospore discharge vary from 0.005 cm to 0.1 cm. So far as asci are concerned, the distance of discharge may be as low as 0.1 cm but is more frequently of the order of 1 cm: in *Dasybolus immersus* a horizontal throw of 60 cm has been measured. The performance of *Daldinia* can easily be seen if a median slice a few millimetres thick is cut from an active stroma and laid on its side overnight on a horizontal sheet of glass. There develops, parallel with the perithecia-studded edge of the slice, a thick black deposit forming a band about 1 cm wide separated from the stroma by a spore-free zone with a width of about 0.2 cm (figure 3). The fact that the spores are spread out in this way is easy to explain. The contents of the ascus may stick together on discharge as a relatively large projectile of eight spores, or break up into smaller projectiles of fewer spores, even single ones. For a given initial velocity the distance (d) of horizontal discharge of microscopic spherical projectiles is given by $d = Kr^2$, where K is a constant and r the radius of

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the projectile. Thus with a given initial velocity of discharge the larger eight-spored projectiles will travel considerably further than a projectile consisting of a single spore. In conformity with this, microscopic examination of the spore deposit shows that towards the outer fringe the spores are mainly in groups of eight, while on the inner fringe single spores predominate [7]. As in *Ganoderma*, the spore output by *Daldinia* is very great. A single stroma of average size may liberate 100 000 000 spores overnight.

It has already been remarked that the stroma lasts for only a single season. In Britain, it appears and grows rapidly to its full size during the damp but still warm weather of September. The perithecia, however, do not mature until the late spring of the following year. Once spore discharge commences, usually early in May, it continues until September, and as with *Ganoderma* it appears to be independent of external water supply [8]. *Daldinia* seems to be a xerophyte of the *Cactus* type. The stomatal tissue represents a water reserve on which the perithecia draw, so that discharge can take place even in the driest weather. If a stroma is detached from the tree in early summer and placed in a dry room, it will continue to discharge spores for several weeks. Its initial specific gravity is just over 1.0, but when discharge ceases this is reduced to less than 0.3, hardly any change occurring in the actual volume of the stroma. When attached to the tree there is evidence to show that, as the water reserve is used up, it is replenished from the host [8]. In its lack of reliance on external water *Daldinia* appears to be unique, and it is quite unlike other Pyrenomycetes, which can discharge their spores only after wetting by rain.

Another outstanding feature of *Daldinia* is the periodicity of its spore discharge. It is nocturnal. The vast majority of the spores are discharged during the period from 9 p.m. to 9 a.m., and very few from 9 a.m. to 9 p.m. Periodicity of discharge seems to be a feature of many Pyrenomycetes, although not all are nocturnal. *Sordaria fimicola*, for example [9], a very common dung species, is diurnal. In the Basidiomycetes, on the other hand, daily periodicity of discharge does seem to occur.

In *Daldinia* the periodicity has been investigated to some extent [10]. If a stroma is kept continuously in the dark at a constant temperature, periodic spore discharge continues for from 4 to 10 days (figures 4 and 5). If kept in continuous light, periodic discharge also continues, but for a shorter time. Both in continuous light and in continuous darkness the discharge rate ultimately settles down to a steady level with no clear periodicity. If, however, the old periodic conditions of illumination are again imposed, the periodic discharge immediately begins again. We have in *Daldinia* an example of an endogenous rhythm continuing after the periodic conditions have ceased to operate. A very similar state of affairs has been found to occur in the coprophilous phycomycete *Pilobolus* [11, 12]. However, in *Sordaria fimicola* there is no endogenous rhythm [9].

In *Ganoderma applanatum* and in *Daldinia concentrica*, chosen as representatives of Basidiomycetes and Ascomycetes, we see two rather different types, each discharging vast numbers of spores. To some extent these two examples are rather unusual, particularly in their water relations, but they serve to show how highly organized are the larger fungi in relation to spore dispersal.

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Plants and their water supplies

J. P. HUDSON

The practice of irrigation is so ancient, and such vast sums are now being expended on new irrigation schemes, that it might be supposed that the basic principles governing the efficient supply of water to plants are well known. In fact, however, for many crops some seemingly simple questions, such as the best time to apply water, cannot yet be answered. This article reviews some recent work in the field of irrigation research and stresses the necessity for more experimental work if full value is to be obtained from money spent on irrigation schemes.

The capacity of a plant to grow is limited by its heredity, and nothing the farmer can do can increase yield beyond that level, but up to the limit set by genetics the harvest produced by any crop is determined by its response to the environment. The plant environment is extremely complex, and is affected, among other factors, by the weather, soil, cultural practices, competition with other plants, and the incidence of diseases and pests. Yield is determined by the net effects of all these factors on growth, and the amount by which actual yield falls short of possible yield reflects the extent to which the controlling factors themselves fall short of the ideal.

Some factors, particularly those concerned with light and temperature, are difficult to control, and the farmer philosophically plans his cropping to make the best of local conditions, but other factors may be more readily controllable. Where this is so, it is important to know two things. Firstly, at what level each particular factor is likely to produce the best yield, and secondly, how far towards that level it will pay the farmer to go.

Because of their natural tolerance to sub-optimal conditions, plants can produce reasonable yields under moisture conditions that are far from ideal. It is not easy for a farmer to assess the loss of yield caused by incorrect irrigation practices, because he usually has no standard by which to form his judgment. If plants were less robust, and soils less accommodating, so that crops died at the first sign of adverse conditions, we might by now have learned how to grow them perfectly. In fact, agriculture depends on the resilience of plants to adverse conditions, yet that very characteristic often masks responses that could point the way to improved methods of management.

IRRIGATION MANAGEMENT

So far as water is concerned, irrigation requires three questions to be answered. (1) When should

water be applied? (2) How much water is needed? (3) What is the best way to do the minimum damage to soil structure when putting water on the land? The first is a question of crop physiology, the second is largely dependent on meteorological conditions, while the third problem lies in the fields of soil science and engineering. Although the three questions are listed in their logical sequence, and perhaps in their order of relative importance to the farmer, the present state of our knowledge of the answers is anything but logical.

Irrigation engineers have provided admirable solutions to the third of these questions. The problems of water conservation, distribution, and application to the land are well understood, and efficient methods of irrigation are available to meet the needs of most farmers, once those needs can be formulated precisely. Soil scientists are able to describe the characteristics of a soil in terms, such as infiltration rates, moisture-holding capacity, and rates of water movement, which enable the best method of water distribution to be specified for each type of soil.

In the past, the second question has been answered largely by guesswork. If the guess was wrong and too little water was applied, then plant growth would be depressed through lack of moisture, since the soil would not be adequately re-wetted and part of the root zone would remain too dry for roots to function well. On the other hand, application of too much water might result either in disastrous waterlogging or in loss of surplus water to drainage, carrying with it valuable plant nutrients.

Ideally, the object at each irrigation is to re-wet the whole volume of soil occupied by roots to the condition of moisture optimal for the growth of the plant concerned. This is usually taken as being the 'field capacity', i.e. the maximum amount of water which a well drained soil can hold against gravity.

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FIGURE 1 – Glasshouse subdivided into brick-lined beds for experimental work on the water-relationships of tomato plants.

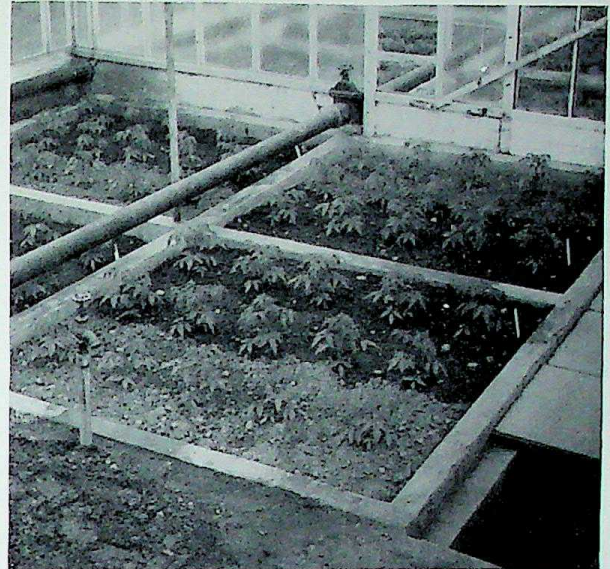


FIGURE 2 – Four lysimeters with concrete bases and drains leading into deep trench (on right) where drainage water from each bed can be collected and measured. Each bed is subjected to a different water regime throughout the life of the plants, with a sub-treatment in each lysimeter in the early stages.

Simple and obvious though it seems, there is still no really satisfactory way of deciding in the field how much water should be added, but in the last few years a new approach has yielded rewarding results. It has been shown by H. L. Penman [1] and others [2] that the rate of moisture loss from a soil can be deduced from a study of certain readily recorded meteorological data, such as hours of sunshine and rate of precipitation, without direct measurements of the actual moisture status of the soil. This is a tremendous step forward, since the necessary local meteorological observations can easily be made and from them information can be supplied to the farmer on the rate of water loss from his own particular soil. He can thus be advised how much water he should apply to ensure adequate re-wetting without waste.

WHEN TO WATER

This kind of knowledge does not, however, indicate when to water, which is an essential key to successful irrigation.

Plants suffering from severe shortage of water show various visual symptoms of distress, the most obvious of which is wilting of soft stems and leaves. However, before these drastic visual symptoms occur there may be a marked slowing down of growth. Since it is difficult to assess retarded growth, farmers and gardeners often believe that so long as a plant looks all right it is growing well. This belief suggests that there is no need to apply irrigation water until just before plants wilt; it will certainly prevent them from ever showing

visible signs of distress and will often produce apparently satisfactory yields. Indeed, workers of the University of California [3] have produced a good deal of experimental evidence that appears to support the view that there is little point in irrigating until nearly all the available water has been taken from the soil. This view sanctions the application of irrigation water in relatively infrequent, but heavy, doses.

But there is also much evidence [4] that appears to conflict with this view, and suggests that, as a soil dries out, growth falls off long before plants start to wilt. In other words, yields may be seriously reduced by shortage of water without the plants ever having shown any visible signs of distress at all.

Results of five years' experiments at Sutton Bonington [5, 6] have suggested a possible bridge between these two apparently contradictory results, both of which may be valid in different circumstances. It has been found that the same volume of water may produce different yields, depending on whether it is applied in a few heavy applications or many lighter ones, a result that may obviously be of the greatest importance.

The water in a soil that is available to plants lies between two convenient but rather ill-defined limits, namely field capacity and permanent wilting point. The latter is the point at which plants flag and will not recover unless they are watered.

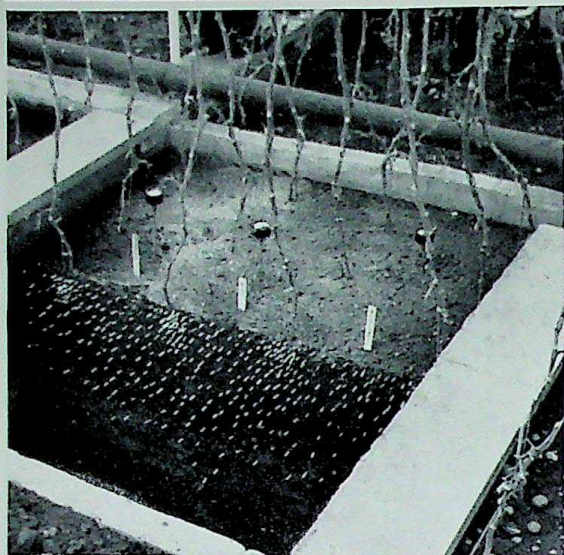


FIGURE 3—Tomato plants excavated at the end of the growing season to study effects of the water regime on distribution of roots. Each white peg on the exposed face marks the position of four roots. Note the vacuum gauges of tensiometers installed to measure soil moisture tensions.

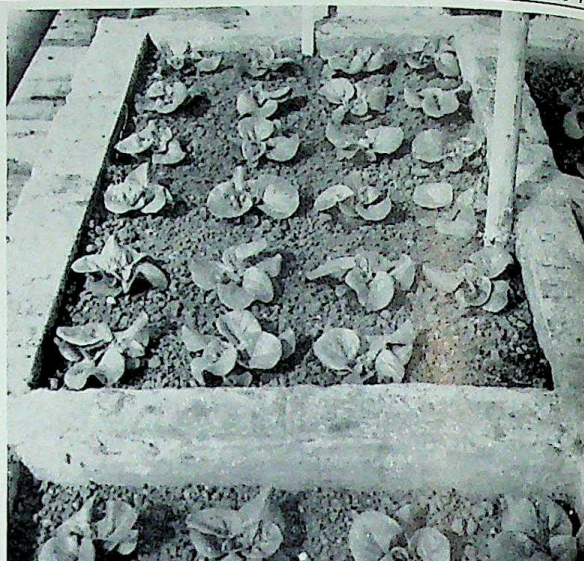


FIGURE 4—Lettuce plants growing in a brick-lined bed, subjected to a particular water regime. Corner plants were removed at intervals of seven days to compare growth rates under different systems of irrigation.

SOIL MOISTURE TENSION

The progress of water uptake from a soil can be followed by measuring one or other of the characteristics of soil moisture [7]. Measurement of soil moisture tension is useful, because it is related to the forces that must be overcome when a plant takes up water. One convenient method of assessing tension at the wetter end of the 'available' range is to install soil moisture tensiometers. These consist of unglazed porous porcelain pots connected by tubes to gauges or manometers, each instrument being filled with water and its pot buried to the required depth in the soil. It is assumed that the water in the instrument becomes continuous, through the pores of the pot, with the moisture filling the fine soil capillaries. As the soil dries out, the tension of the remaining moisture in the soil increases, is transmitted to the water within the tensiometer, and is recorded by its gauge, which responds to rewetting of the soil by returning to a low reading (figure 5). Other methods are more useful for recording moisture tension at the drier end of the 'available' range, where tensiometers are not suitable.

The vital information of when a plant should be watered if its growth is not to suffer, must be gained by experiments in which comparable plants are grown under different, definable, and reproducible water regimes. Techniques for such studies have been worked out; they include one, based on the use of soil moisture tensiometers, which has

given good results over a number of years and has helped to elucidate the relationships between several species and their water supply [8] (figures 1-4).

In each regime a predetermined moisture tension is chosen, beyond which the soil is not allowed to dry at any depth or at any time. Since this indicates the maximum degree of dryness, it follows that most of the soil will dry out less, and the moisture content in areas where there are few roots will change little between one irrigation and the next (figure 7). An essential part of the technique is the assessment of effects of different water regimes on growth as well as on final yield, since the latter is too insensitive an indicator and may not reveal variations in the effects of moisture on growth at different stages in the life cycle.

Using such techniques it is possible to study the relationship between the growth of a plant and its water supplies. The most straightforward relationship occurs in the case of annual crops which are sown *in situ* or planted out as small plants. Experiments with young plants of lettuce (*Lactuca sativa* Linn.) or tomatoes (*Lycopersicum esculentum* Mill.), set out in beds of soil at field capacity, have shown that, as would be expected, the area immediately around each plant soon starts to dry out as the first roots extract moisture. However, roots are meanwhile growing steadily, both vertically and horizontally, into new areas of soil which are still at field capacity. Each root, as it grows,

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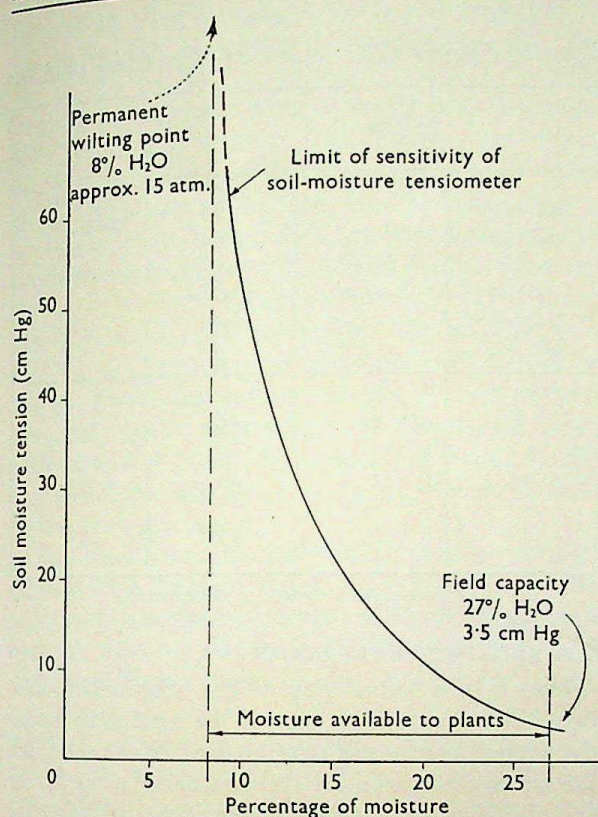


FIGURE 5—Soil moisture characteristic curve for a coarse sandy loam soil (Sutton Bonington).

develops a system of root hairs which enables it to extract water from a cylinder of soil around itself. Thus the young plant has an increasing number of roots which are rapidly reaching out into new soil containing ample supplies of moisture, even though the soil around the base of the plant is soon depleted of most of the available water.

During this phase in the establishment of a plant, when roots are still growing strongly into damp soil, growth seems to be little affected by high moisture tensions in the shallower layers. Table I shows results in one of a number of experiments with lettuce (A. M. Majmudar); similar results have been obtained with young tomato plants (P. J. Salter and A. E. Moorat). It seems that these plants can make optimal growth provided that part of their root systems is in contact with moisture at low tension, even though other parts of the same root systems are in much drier soil (figure 6). Plants respond little to irrigation water applied during this phase.

However, by the time the whole available soil has been occupied by the roots of a short-term crop the rate of new root-growth is probably slowing down, and the resources of the plant are being

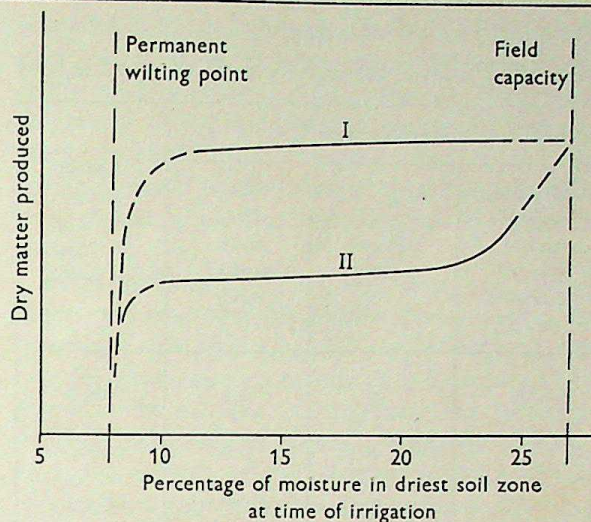


FIGURE 6—Curves relating the relative response of plants to the degree of dryness allowed to develop in the zone of maximum rooting (i.e. the driest layer of soil) before irrigation. Curve I: While roots are still growing into new areas of moist soil (lettuce and tomatoes). Curve II: When the whole available rooting zone has been occupied by roots (tomatoes).

diverted to the production of fruits or storage organs. By this time, when fewer roots are elongating rapidly, the plant may respond quite differently to soil moisture. Experiments with tomatoes in the fruiting phase (P. J. Salter) have shown that the rate of both vegetative growth and fruit production falls off when high moisture tensions are allowed to develop between irrigations. Indeed, growth may then be retarded by levels of moisture tensions that would have little effect on growth at an earlier stage in the life cycle, and in mature tomato plants it seems that optimal growth and yield are possible only if the soil is maintained in a relatively wet condition, virtually at field capacity, by frequent light irrigations (table II). It must be emphasized that this response is not to total quantity of water applied but to frequency of application. Water applied little and often produces more vigorous growth than less frequent but heavier applications of the same total volume of water.

With perennial crops the situation is still less straightforward than with annuals, since a plant may start the growing season with a well established root system that already occupies most of the available soil. In such cases there is no considerable new volume of damp soil into which roots can grow in search of water, and the plants may react more sharply than newly planted crops to rising moisture tension, but this type of relationship has not yet been fully worked out.

TABLE I

Effects of different water regimes on Cheshunt 5b lettuces

Irrigation data			Average fresh weight (g) per head (48 plants)
Maximum moisture tension allowed to develop (cm Hg)	Times watered	Total water applied (cm)	
5	5	4.2	193.0
9	4	5.4	192.5
20	2	3.8	194.5
60	0	nil	197.3

Differences in yield are not significant.

TABLE II

Effects of different water regimes on Ailsa Craig tomatoes

Irrigation data			Average yield (kg) of fruit (50 plants)
Maximum moisture tension allowed to develop (cm Hg)	Times watered	Total water applied (cm)	
7	88	42.2	4.7
15	11	46.3	3.9
30	9	45.0	3.6

Differences in yield are significant.

TOTAL SOIL-MOISTURE STRESS

Another aspect of the plant-moisture relationship is intimately linked with moisture tension. The ease with which a plant can extract water from the soil depends on the 'total soil-moisture stress' [9], which is the sum of the forces concerned in the moisture tension and the osmotic pressure of the soil solution. The latter component, depending on the amount of soluble salts dissolved in the soil water, is usually negligible in damp soils of high rainfall regions, where salts are readily leached from the soil by the excess moisture that passes through the soil to drainage. It can, however, become an important factor in low rainfall areas, where salts are not washed out, or in non-saline soils that are allowed to dry out. The total amount of soluble salts in a soil does not vary as the soil dries out, but the concentration of the solution rapidly increases. Thus both the moisture tension and the osmotic pressure components of the total soil-moisture stress increase rapidly in a drying soil.

Salts tend to accumulate in soils under irrigation in arid zones, and this factor has to be taken into account in deciding irrigation practices. The difficulty can to some extent be overcome by skilful control of the timing and amounts of irrigation. For instance, the results of unpublished work with tomatoes (D. W. T. Clay) have shown that reasonable yields can be produced, in soils containing surprisingly high burdens of soluble salts, provided the soil moisture tension is maintained at a low figure by frequent light irrigations.

CONTROL OF IRRIGATION

How can a knowledge of the relationship between plants and soil moisture be used to increase the output from world agriculture? Huge schemes are being developed for the control of river levels and the tapping of new sources of water that can be distributed in an orderly way for irrigation, but unless the three questions posed at the beginning of this article are answered correctly on a field-to-field basis the water will not be used to

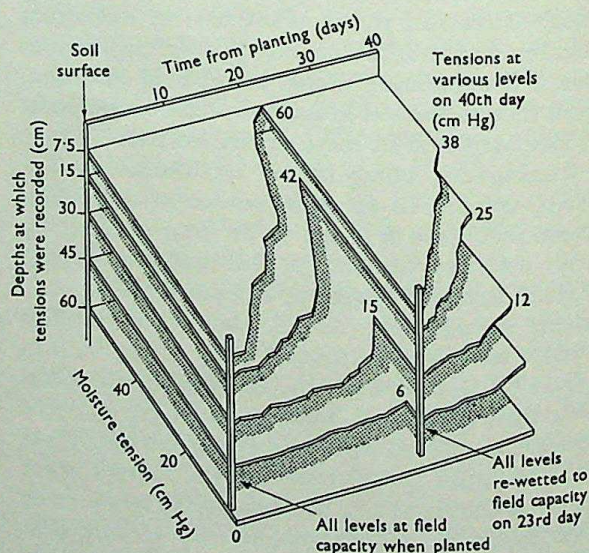


FIGURE 7—Model showing moisture tensions recorded at various levels in a block of soil which was being gradually occupied by the roots of a lettuce crop planted on the first day and harvested on the fortieth. There were few roots at the lowest levels.

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best effect. Application of water too early, before plants need it, may actually depress growth. The use of too much can depress growth by water-logging or causing wasteful losses into drainage. Too frequent irrigation can cause unnecessary damage to soil structure. Failure to apply water as soon as plants need it may lead to loss of growth and yield, even though the crop does not appear to be suffering from drought. Thus the use of water too early, too late, too often, too infrequently, too liberally, or in insufficient quantity can all have the effect of reducing the yield per unit volume of water. In the last resort, the effectiveness of even the most brilliant schemes of large-scale river control will depend on the policy followed in the details of the supply of water to the individual consumer—the plant.

The most effective distribution can be planned only from a detailed knowledge of the particular crop and its responses to the moisture tension and osmotic pressure of the soil solution, which may vary at different stages in the development of the root system. Perusal of the literature of irrigation research leaves one dissatisfied with much of the work, for it has been based on techniques too insensitive to reveal the details of the dynamic and complex relationships between plant, soil, moisture, and salts. Excellent work has been done on these relationships for some crops, notably those, like cotton and sugar, which are important in world trade and have well developed research organizations. There is, however, a lack of information on many other crop plants, especially those which are grown on a small scale for local

consumption, even though these often provide the staple foods of the peoples concerned. There certainly does not seem to be sufficient information at present about many of the important irrigated crops to ensure that water is used to the best advantage and to serve as a proper basis for effective planning of the distribution of irrigation water.

Many irrigation systems are, of course, already highly efficient and producing heavy yields, but others are not producing the crops that could be expected from a given expenditure of water. There seems to be no way of acquiring the necessary information except by critical experiments on each crop. These will, no doubt, confirm the efficiency of some irrigation practices but in other cases may well show that heavier yields could be obtained at no extra cost by a different system of management.

The need for more experimental work is urgent if full use is to be made of the water supplies already available and those to be developed in the new plans for river control. Its aim must be to show how water can be applied at just the right time, in the right amounts, and in the right way, thus ensuring that irrigated crops make the greatest possible contribution to feeding the people of the world.

ACKNOWLEDGMENT

The experimental work on tomato and lettuce plants referred to in this article was carried out in the Department of Horticulture, Nottingham University, by Dr P. J. Salter, Dr A. M. Majmudar, Mr D. W. T. Clay, and Mr A. E. Moorat, to whom I am very happy to pay tribute.

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The molecular basis of heredity

W. G. OVEREND and A. R. PEACOCKE

Nucleic acids play an essential role in genetic processes, and chemical investigations of their structure have progressed sufficiently for general formulae to be proposed for them. Progress in these two fields is here reviewed, and it is concluded that although the facts of heredity cannot yet be completely explained in terms of molecular structure the gap between molecular and cytological levels of organization is not unbridgeable.

It is well established that chromosomes carry the genes that are the units of heredity. The genic material has been examined, and deoxyribonucleoprotein, the main constituent of chromosomes, has been studied closely. The investigations have been fruitful, and it now seems agreed that this nucleoprotein is significant in genetic processes and that the nucleic acid is particularly important.

Proteins are frequently considered to be the most important substances in living matter, but it is now clear that the nucleic acids must rank at least as their equal. A combination of cytological, chemical, and genetical experiments has led to recognition of the importance of nucleic acids in hereditary processes [1]. Some of the results of these experiments will be described briefly here, but in this article a comprehensive account of all the biological work is neither feasible nor appropriate, and our main object is an attempt to correlate the biological function of nucleic acids with knowledge of the structure of their molecules.

NUCLEIC ACIDS IN HEREDITY

The suggestion that deoxyribonucleic acid (DNA) is a genetically active material is supported by its localization in cells: cytochemical experiments have shown DNA to be located in the chromosomes, the cellular structures that carry the genes. It is recognized that chromosomes have other constituents, especially histones and other proteins, but this does not invalidate the above statement. Quantitative cytochemical measurements of DNA distribution reinforce the proposal of a genic function for it. It has been demonstrated [2] that the amount of DNA is essentially constant in the diploid somatic nuclei of various tissues within a species, and is present in half-quantities in the haploid sperm cells. On the other hand, the various proteins of the nucleus do not appear to have the distribution expected for genic material.

The discovery of the biological phenomenon of 'transformation', and of the nature of the transforming principles, afforded the first possibility of a chemical approach to the problem of heredity. The initial discovery did not attract much attention. In 1928 F. Griffith [3] reported that from mice injected with living non-encapsulated rough-colony type (R) *Pneumococci* mixed with heat-killed encapsulated smooth (S) variants it was possible to recover living (S) *Pneumococci*. Once the new feature (production of the capsule of specific type) was established, it was retained and reproduced in subsequent generations, as if a new gene had been added to the genetical make-up of the receptor cells. When killed by heat, the transformed cells would themselves induce transformation of R cells in the same way as the original S cells did. The conversion could be brought about in an R pneumococcal strain which was never observed to change or mutate spontaneously into the smooth type or any other. Although the experiments were confirmed by other workers, doubts persisted, and it was contended that the seemingly heat-killed preparations contained some heat-resistant bacterial forms, and that a 'revival' of the S cells, rather than a 'transformation' of R cells, would account for the results. Subsequently, the transformation was demonstrated *in vitro*, and soon afterwards it was found that the presence of the whole 'donor' S cell was not necessary. Transformation of R cells into the S forms was achieved with aqueous extracts of heat-killed S cells: the extracts were passed through bacterial filters before being tested for transforming activity. It was not possible to exclude a filterable virus as the responsible agent until 1944, when O. T. Avery and his collaborators [4] purified the extract and found that the 'transforming principle' had all the properties of a highly polymerized DNA. The conclusion that the isolated material was DNA was based on elementary analysis, chemical tests,

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serological examination, and the observation that of all enzymes investigated only deoxyribonuclease was capable of destroying its biological activity. On heating the transforming principle, loss of biological activity commences at the same temperature (81° for 1 hour) as that at which the viscosity of the preparation begins to decrease. This behaviour towards heat is characteristic of nucleic acids, but most known proteins cannot withstand such treatment. The pH values at which the transforming activity begins to decrease, on both the acid and alkaline side, are the same as those at which the viscosity of DNA begins to decrease. Finally, transforming material can now be purified to the stage at which the presence of protein can be excluded on purely analytical grounds. All these results (for a full account see [5]) indicate that the transforming principle is DNA, and no conclusive evidence to the contrary has ever been presented.¹ It has since been discovered that in addition to capsule formation a number of other characters in *Pneumococci* are transformable. Reproducible transformations are known only in bacteria, however, and the phenomenon has not been observed in more differentiated organisms.

It is interesting to speculate whether an active DNA preparation made from many presumably identical cells represents a single chemical species or is a mixture. Although a donor may be able to transform an acceptor strain in respect of several different characters, in general each of the transformed cells is altered only in respect of one character at a time. The preparation of the transforming principle thus behaves like a mixture of different transforming particles. Doubly transformed cells occur as rarely as predicted from the probability of two independent particles entering the same cell. For this reason it is usually assumed that the 'markers' must be present on different molecules; as will be described later, the structure of DNA is capable of sufficient variation to account for this.

To summarize, there are many features of the phenomenon of transformation which are not understood, but the transforming principles do

appear to be hereditary determinants, since they induce specific inheritable characteristics and initiate their own replication. These principles have been extracted from cells and identified as DNA by a variety of accepted techniques. They can be examined by the methods, suitably modified, developed to investigate the physical chemistry of nucleic acids and they can be chemically changed *in vitro*; after reintroduction into the cell the relationship between structural change and biological function can be studied. It is therefore clear that the application of chemical methods to at least one facet of heredity is possible.

Investigation of infections of *E. coli* with bacteriophages of the type T has yielded extremely interesting results about the production of new specific forms of DNA within a cell already organized for the biosynthesis of the host's own type of DNA, and provides another pointer to the genetic significance of this nucleic acid. The T-coliphages which lyse the host bacterium *E. coli* are principally composed of protein (about 60 per cent) and DNA (about 40 per cent), together with a small amount of lipid. It seems that the DNA is mechanically, rather than chemically, confined by the protein, which exists largely as a membrane surrounding a mass of free or loosely bound DNA. Although this is not a complete description of T-phage structure, it makes it possible to distinguish the functions of the protein and DNA components respectively. When coliphage is added to *E. coli* cells in a suitable environment, the phage particles are rapidly adsorbed on the bacteria. Adsorption soon becomes irreversible and the bacterium is killed. After a latent period, the cell lyses and a large number of new phage particles are liberated. A. D. Hershey and M. Chase [6] have demonstrated that the DNA plays a major role in this process. By means of isotopic tracers it was found that the DNA of two other infecting phages (T_2 and T_6) enters into the infected cell, while the protein component remains outside.

It thus appears that the DNA of the phage is capable of carrying forward the process of infection and that the protein is not required after the DNA has been introduced into a host cell. In the subsequent stages of T-phage reproduction, quantities of phage-protein membranes and phage DNA are synthesized in the infected cell. These are specific macromolecular materials, different from any of the components of the non-infected host. It is generally assumed that such species-specific materials are produced under the influence of specific genetic determinants, in this

¹ For successful transformation of *Pneumococci* other factors besides the transforming principle need to be present. These agents are believed to produce 'sensitization' of receptor cells, a temporary change of unknown nature. For transformations of *Haemophilus influenzae* and *Neisseria meningitidis*, however, no need for additional factors (other than those in the medium) could be established, and so it appears that these factors are not primarily responsible for the transformation.

case the DNA of the phage. Although the detailed biochemical processes have not been worked out, it seems that the DNA of an infecting T-coliphage controls the nucleic acid and protein metabolism of the host cell much as if it were a genetic entity dominating the host genes.

In the present state of knowledge, it would be unwise to conclude from observations such as the above that chromosomal DNA alone carries the specific genetic determinants in higher organisms. There are indications that other factors may then be involved, but equally there are observations which point to *in vivo* genetic properties attributable to DNA. In this respect the following experiment may be mentioned. Intact cells in fungi and corn were irradiated with ultra-violet light, and the wavelength most effective for producing genic mutations was found to be the same as that at which the absorption of the ultra-violet light by DNA was greatest. Some evidence of the chemical nature of genes can be found in the effects of certain mutagenic agents like the nitrogen and sulphur mustards, to which the nucleic acids are highly susceptible: X-rays likewise have disruptive effects on DNA. It may be a coincidence that the cytogenetic action of the sulphur and nitrogen mustards and of X-rays is to produce chromosome breaks and other effects, but it is an attractive hypothesis to relate the sensitivity of DNA towards these agents with chromosomal changes: this theme will be developed more fully later.

In nature, there are two types of nucleic acid, namely deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). So far, this article has been limited to DNA, but investigations on RNA are also important. Description of these must, however, be limited to a brief mention of some results concerning virus multiplication. In common with other self-reproducing or protein-synthesizing units, plant and animal viruses are nucleoproteins. Although animal viruses contain RNA or DNA or both, the plant viruses contain RNA exclusively: the RNA content ranges from 6 per cent in tobacco mosaic virus up to 35 per cent in turnip yellow mosaic virus. The fact that substances as relatively simple as ribonucleoproteins are able to reproduce themselves, and are thus endowed with genetic continuity, is of the utmost importance. Moreover, from work with turnip yellow mosaic virus it was concluded that there is some evidence that the nucleic acid is in fact the substance controlling virus multiplication [7]. Experiments with tobacco mosaic virus showed first that the protein could be changed chemically without

affecting the activity of the virus, and then that part of the protein could be removed without destroying the activity. Very recently A. Gierer and G. Schramm [8] have obtained evidence that after complete removal of the protein from the virus nucleoprotein the RNA alone is still infectious and appears to maintain the genotype.

Many published papers lead to the conclusion that RNA plays an essential role in protein synthesis in cells of all types. Little is known of the precise relationship between the DNA of the nucleus, which remains relatively constant, and the RNA of the cytoplasm, which appears to be more directly involved in protein synthesis. Recently, it has been claimed [9] that direct evidence has been obtained that cytoplasmic RNA or its precursor is synthesized in the nucleus and transmitted to the cytoplasm. It is possible to speculate on the means by which the specific nucleotide pattern preserved from one generation to the next in the DNA can be transmitted to the RNA to be operative in protein synthesis, but in the absence of precise knowledge of the molecular configurations of RNA and of nucleoproteins such speculations are of doubtful value.

STRUCTURE OF NUCLEIC ACIDS

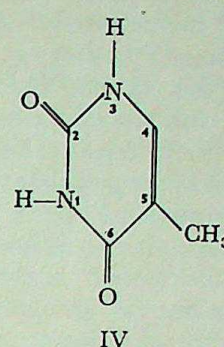
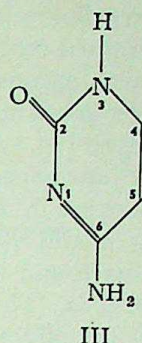
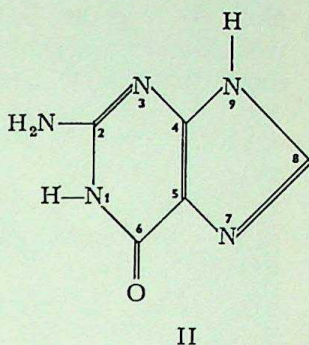
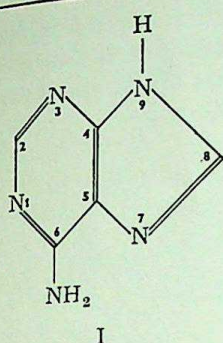
The composition of nucleic acids has been deduced from examination of hydrolysates obtained both chemically and enzymically, and it appears that the successive stages of degradation are as follows:

Nucleic acid $\rightarrow$ simple nucleotides
 $\rightarrow$ nucleosides + phosphoric acid
 $\rightarrow$ purine and pyrimidine bases + sugar

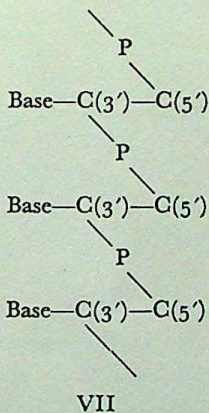
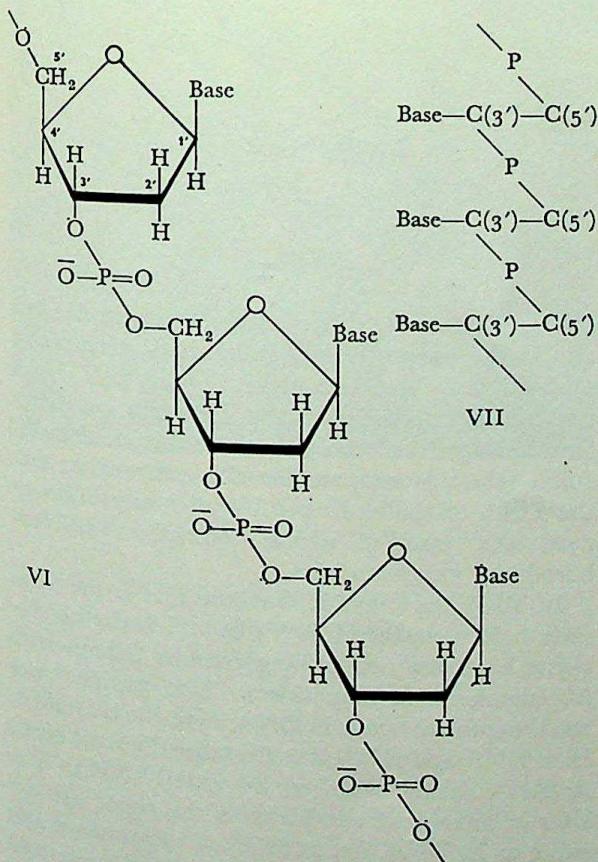
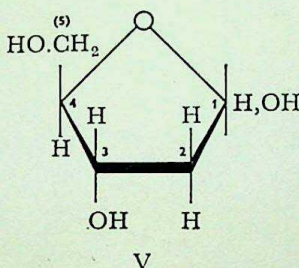
The purine bases obtained from DNA are adenine (I) and guanine (II), and the pyrimidine bases are cytosine (III) and thymine (IV). Some samples of DNA contain small amounts of 5-methylcytosine, but the occurrence of this is limited, as is that of 5-hydroxymethylcytosine. The sugar is 2-deoxy-D-ribose (V)¹, present in its furanose (5-membered ring) form. The bases are glycosidically joined to the sugar at C(1'), and the linkage is of the β -type. Union occurs at position 9 of the purine bases and at position 3 of the pyrimidine molecules. The sugar-base units are the nucleosides. The simple nucleotides isolated from DNA are nucleosides esterified by phosphoric acid at the primary hydroxyl position C(5') in the sugar

¹ The prime is added to the numbers indicating the carbon atoms in the sugar ring when the sugar is linked to a purine or pyrimidine ring; the numbering of the latter is as shown in formulae (I)-(IV).

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moiety. Acid hydrolysis of DNA produces some pyrimidine nucleoside-3':5'-diphosphates, which indicates participation in the nucleic acid mole-



cule of the C(3') position in the sugar. The formulation of DNA which most satisfactorily accords with all the evidence is a linear unbranched polynucleotide chain (VI, abbreviated as VII) with a recurring 3':5'-internucleotide linkage leading to a molecule of very high molecular weight (5-8 millions).

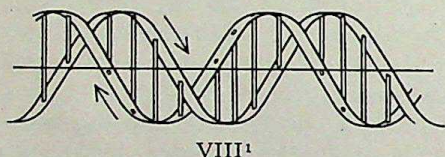
The structure proposed poses two further problems, namely the sequence of bases along the polynucleotide chain and the amount of each base in the nucleic acid: answers to both might be significant in genetics. So far, the determination of nucleotide sequence has barely begun, but much is known concerning the total base composition of various forms of DNA.

Originally it was thought that the bases were present in equivalent amounts, but painstaking analysis of a large number of samples of DNA from a variety of sources has disproved this. The following relationships have emerged from this work:

- Two main types of DNA can be distinguished: the AT type in which the adenine-thymine content outweighs the amount of guanine-cytosine, and the GC type, which occurs mainly in micro-organisms, where the reverse is true.
- The sum of the purine nucleotides equals the sum of the pyrimidine nucleotides.
- The molar ratio of adenine to thymine equals 1, as does the molar ratio of guanine to cytosine (if the DNA contains 5-methylcytosine, the molar ratio of guanine to the sum of cytosine and its 5-methyl derivative equals 1).
- The number of 6-amino groups equals the number of 6-keto groups.

The significance of these relationships becomes apparent when they are considered in conjunction with the elegant X-ray studies of M. H. F. Wilkins, A. R. Stokes, and H. E. Wilson [10]. DNA from a variety of sources such as calf thymus gland, *E. coli*,

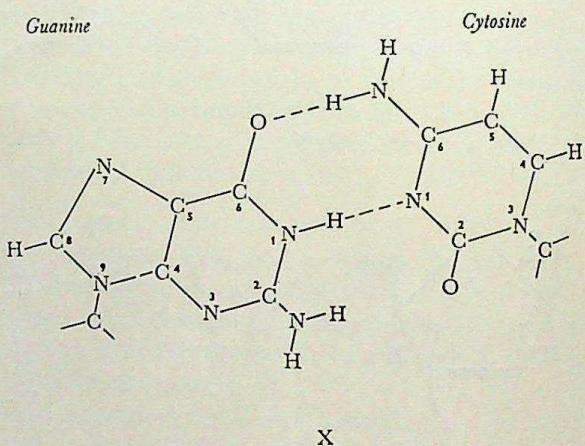
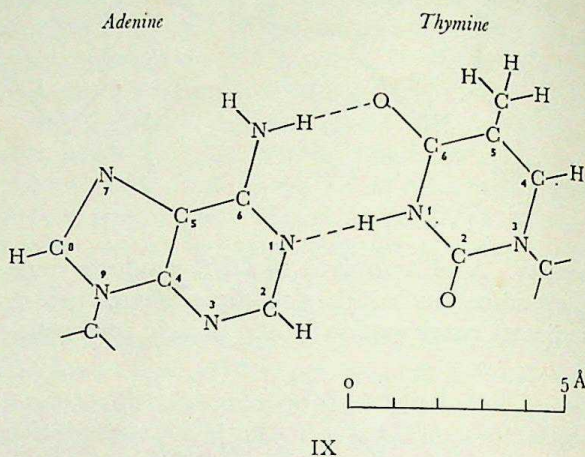
and mouse sarcoma give X-ray diagrams which indicate that they are all constituted on the same pattern. A model of DNA which accommodates the chemical evidence and agrees in essentials with the X-ray data has been developed [10, 11] on the basis of the postulate of specific base pairs. Briefly, it is supposed that in DNA there are in the structural unit two polynucleotide chains which are wound spirally in the same way round the same axis but run in opposite directions. The helical nucleic acid molecule has in the solid state two main configurations: the very compressed, highly crystalline structure (A) and the slightly more extended helix (B), the structure of which is often paracrystalline. Here we are concerned only with the (B) structure. The pitch of the helix is 34 Å and there are 10 nucleotide residues per turn of each strand. Both sugar-phosphate chains follow a right-hand helix and are held together by hydrogen bonds, involving the base residues, to form a double helix of diameter 18 Å. This is shown pictorially in VIII; figure 1 is a photograph of the



double-helical model which has been constructed at King's College, London. There is considerable evidence [12] that the double helix persists as the water content of the DNA increases until the DNA is in solution. Since the phosphate groups are on the outside of the helices, cations have easy access to them; the purine and pyrimidine bases, on the other hand, lie inside the helices and perpendicular to the long axis. A novel feature of the structure is that specific base-pairing is postulated. Examination of models suggests that only the adenine-thymine and guanine-cytosine pairs can bond together and at the same time fit into the structure, a conclusion supported by the analytical data mentioned earlier. The hydrogen bonds lead to the formation of the structures shown in (IX) and (X). This base-pairing accounts well for the observed base ratios, and yet permits the variation of base composition which is found experimentally. It will be noted that in this structure the strands are complementary, since the nucleotide sequence on one strand auto-

¹ The two ribbons symbolize the two phosphate-sugar chains and the vertical rods the pairs of bases holding the chains together. The horizontal line is the fibre axis.

matically fixes that on the other. By the important discovery of DNA fractionation it has been shown that the DNA molecules of one species ex-



hibit demonstrable differences not only in size but also in the proportions of individual purines and pyrimidines. The compositions of whole DNA preparations recorded in the literature are therefore averages and not those of individual molecules. Here is support for the assumption that the DNA of each cell consists of many different molecules, each of which determines different hereditary characteristics.

In RNA the sugar is D-ribose (XI is the furanose form numbered as V) to which the heterocyclic bases are united by glycosidic linkage with β -stereochemical disposition. The purine bases are the same as occur in DNA: cytosine is found in both DNA and RNA, but thymine does not occur in RNA, being replaced by uracil (XII). The sites of linkage of the bases to the sugar are the same as in DNA, i.e. at N(9) of the purines and at N(3) of the pyrimidines. D. M. Brown and A. R. Todd [13] have postulated a recurring

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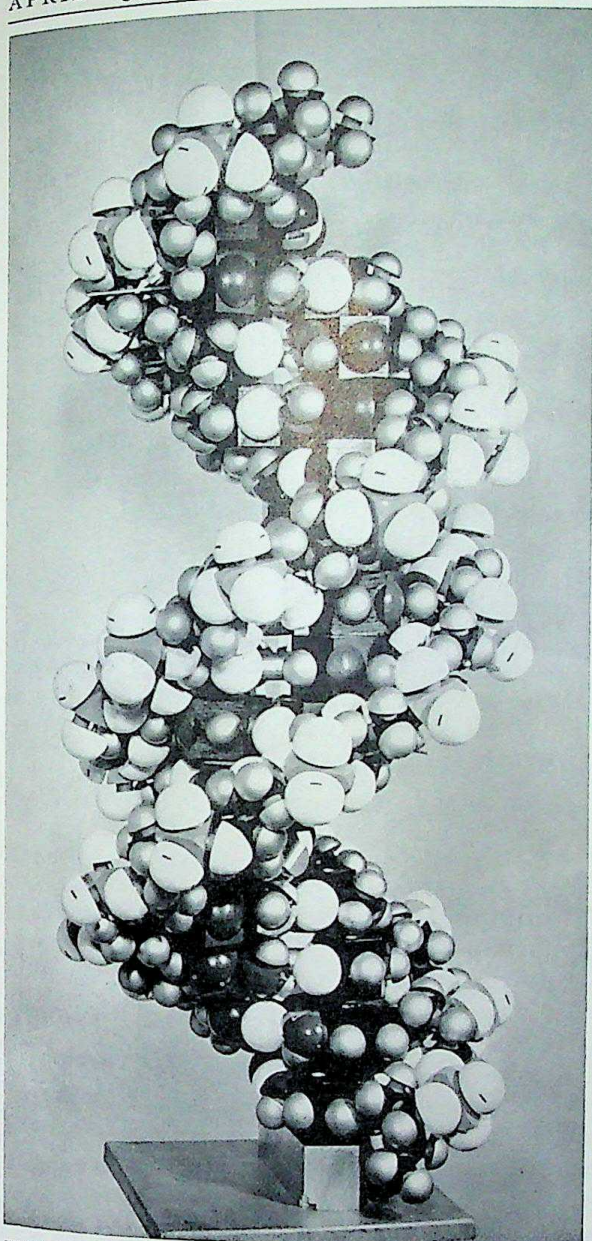
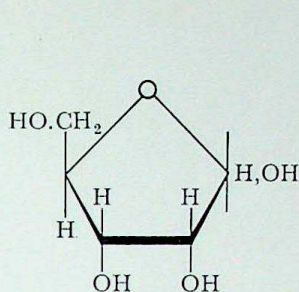
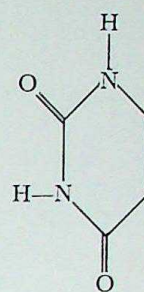


FIGURE 1 - Model of the paracrystalline B form of DNA showing 16 nucleotide pairs. The model (dimensions approx. 109 cm $\times$ 51 cm) is constructed on the scale 2 cm $\equiv$ 1 Å.

3':5'-internucleotidic linkage for the main RNA chain, as shown diagrammatically in XIII. The nucleic acid is shown unbranched: as yet there is no satisfactory evidence for branching in natural RNA, and recent titration evidence suggests the contrary [17]. Todd [14] has pointed out that in theory at least two types of polynucleotide are possible, one bearing the terminal phosphate at C(3') in the nucleoside residue and the other with the terminal phosphate at C(5'). The 'monomers' for the first type would be nucleo-



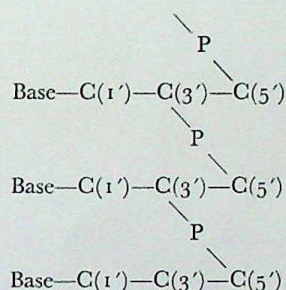
XI



XII

side-3'-phosphates, and for the second type nucleoside-5'-phosphates. End-group assays on RNA have shown examples of both types, but this is hardly decisive, since any degradation of an acid of the latter type would inevitably yield materials with end-groups corresponding to the former

A stepwise degradation method for determining polynucleotide sequence in RNA has been proposed. It has been used successfully with small oligonucleotides, but its application to the nucleic



XIII

acids must await the preparation of these materials in a truly homogeneous condition. Determinations of base composition in RNA are less revealing than with DNA, although it appears that the amount of 6-keto (guanine and uracil) groups equals the amount of 6-amino (adenine and cytosine) groups [15].

Likewise, the macromolecular structure of RNA is less well established than is that of DNA. The molecular weight of RNA, as isolated, is very much less than is found for DNA. So far, the X-ray patterns from various samples of RNA are identical, but the pictures are poor and hard to interpret. Helical structures for RNA have been tentatively proposed. When solutions of the sodium salts of the enzymatically synthesized nucleotide polymers—polyadenylic acid and polyuridylic acid—are mixed, there is a rapid increase in viscosity. From the viscous solution tough glassy fibres can be drawn, and these produce a

well orientated X-ray diffraction pattern with a distribution of intensity characteristic of a helix [16]. These results are taken to mean that the molecule is a two-stranded helix containing one strand of polyadenylic acid and one of polyuridylic acid. The bases, adenine and uracil, link with each other through two hydrogen bonds, in the same way as postulated for adenine and thymine in DNA, with the base pairs stacked above each other roughly perpendicular to the fibre axis. These results show for the first time that it is possible for the backbone of the RNA molecule to assume a configuration not unlike that in DNA, with complementary pairing of the bases. This implies that there may exist a form of the RNA molecule similar to that of DNA, and that this could be the form in which RNA carries out its supposed molecular duplication in the plant and smaller animal viruses.

Recently R. A. Cox and collaborators [17] have obtained electrometric titration data from which it was inferred that hydrogen bonding occurs in a bacterial and a yeast RNA. Whether or not these hydrogen bonds link the same groups as in DNA cannot yet be determined.

NUCLEOPROTEINS

The foregoing structures for the nucleic acids have been derived from work on material which had been separated from the protein with which they are combined *in vivo*.

Several lines of evidence indicate that the double helical DNA structure is present also in nucleoproteins and in relatively intact biological structures such as the heads of fish sperm [18]. The simplest nucleoprotein is that of fish sperm, since in this the protein is composed chiefly of arginine residues and is of low molecular weight (4000–10 000) [19].

X-ray diffraction studies [20] suggest that a fully extended polyarginine chain is wound round the shallower of the two grooves of the DNA double helix, and other physicochemical evidence suggests that it is anchored to it by purely electrostatic forces between the positive arginine groups and negative phosphate groups. It was suggested [20] that since the non-basic amino acid residues (those with uncharged side chains) occur in pairs in protamines, they could possibly be accommodated as loops in the polyarginine chains, perhaps held by interaction with the DNA base rings. The suggestion could possibly apply also when histones are involved instead of protamines, since the former contain a higher proportion of un-

charged side chains. This nucleoprotamine structure explains the long-observed equivalence of the spacing (3.4 Å) between nucleotides in DNA and between amino acids in the fully extended β -form of polypeptides. Optical evidence that the proteins in nucleoproteins are in the β -form has also been obtained [18]. The nucleoprotamine structure affords no obvious explanation of DNA specificity towards proteins, unless this lies in the suggestion about the looped amino acid side chains and their possible interaction with the base rings.

The ribonucleoproteins that have received most attention are the plant viruses. X-ray diffraction studies have shown [21] that the phosphate-sugar backbone chain of the RNA in tobacco mosaic virus is deeply embedded in the virus protein, which is made up of sub-units helically arranged.

BIOLOGICAL ASPECTS

Any theory which attempts to explain the facts of heredity in terms of molecular structure must eventually account for self-duplication, for specificity, and for variation and modification of the genic material. The structure described above for DNA has certain implications, some or all of which may prove to be important to its biological function. Firstly, the double helical structure allows the possibility of self-duplication. In the schematic representation (figure 2), if the sequence I is CTAGGTG¹ . . . and II is the complementary sequence GATCCAC . . ., then if I and II can be separated in some way and acquire new partners in two new double helices, these will have the structures I—II' and I'—II respectively, where the primes indicate new chains. The sequence of nucleotide pairs of the original molecule I—II has therefore reproduced itself in its 'progeny', I—II' and I'—II. Since it is not possible laterally to separate two coils entwined as in the DNA structure, there has been much speculation on possible mechanisms for the replication of DNA. In most of the more plausible mechanisms it is considered that replication proceeds synchronously down the two chains without at any time requiring the existence of free single strands.

Secondly, there is the possibility of variation. Since isolated DNA contains 10^4 or more complementary nucleotide pairs there are of the order of $4^{10\,000} \approx 10^{6000}$ possible nucleotide sequences for individual DNA molecules. The nucleotide sequence seems to be the only possible basis for the specificity of DNA molecules, but this must

¹ C = cytosine or 5-methylcytosine, T = thymine, G = guanine, and A = adenine nucleotide residues.

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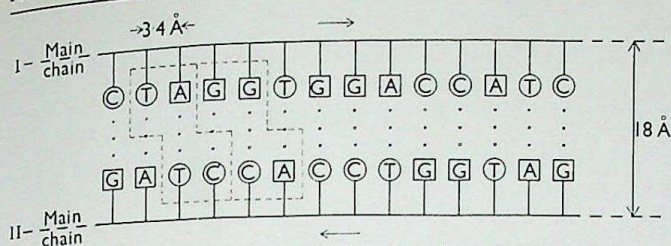


FIGURE 2 - Diagram of two possible complementary base sequences in the double-helical deoxyribonucleate molecule. $\square$ Purine nucleotide unit (A = adenine residue, G = guanine residue). $\circ$ Pyrimidine nucleotide unit (T = thymine residue, C = cytosine or 5-methylcytosine residue) . . . Hydrogen bond systems (see IX and X) cross-linking the two helical main chains, represented by continuous straight lines. Arrows show directions of the main chains. Helix diameter $18 \text{ \AA}$; the internucleotide distance of $3.4 \text{ \AA}$ along the axis refers to the paracrystalline B form. Broken lines enclose two hypothetical 'coding' units.

manifest itself eventually in specific proteins with particular amino-acid sequences. The question arises: 'How can the sequence of more than twenty different amino acids be guided by only four kinds of base?' To answer this P. C. Caldwell and C. N. Hinshelwood [22] suggested that the 'code' for each amino acid might consist of two adjacent nucleotide units, and G. Gamow [23], employing the double helical model, has suggested a triplet code, since there are twenty possible combinations of bases (disregarding order), taken three at a time from the four available. Figure 2 shows, enclosed in broken lines, two such groupings of three independent elements; it must be remembered that the middle pair constitutes only one independent element. Analysis of the frequency with which any one amino acid follows another in the few simple proteins for which the sequences are known, indicates that these sequences are entirely random, and it is suggested that the nucleotide triplets do not overlap.

Thirdly, we must consider the possibility of modification of the DNA molecule. Here various possibilities suggest themselves.

(a) As stated, the internucleotide phospho-ester linkages can be destroyed by a variety of agents, including ionizing radiations and enzymes. When single phospho-ester linkages are broken by these last two methods, it has been shown [12c, 24, 25] that the molecule separates into two parts only if the breaks occur at opposite, or nearly opposite, positions in the two chains (e.g. α_1, α_2 , figure 3). If the breaks in opposite chains (e.g. α_1, α_4) are separated by more than two or three [25] hydrogen-bonded pairs the molecule remains intact, although its shape may change. Breaks in the same chain (e.g. α_1, α_3) need not cause detachment of the intervening units and are revealed only by subse-

quent rupture of the hydrogen bonds. The effects of sulphur and nitrogen mustards have been thought to be caused by rupture of internucleotide linkages by first forming unstable tri-esters of the phosphoric acid residues.

It is possible to find a formal similarity between the consequences of internucleotide bond rupture in DNA caused by ionizing radiations and the chromosomal changes these agents evoke. Thus if the segment produced by breaks α_1 - α_2 , α_4 - α_5 rejoined, so that the atoms involved at α_2 were then at α_5 and those at α_1 were at α_4 , there is a state of affairs formally similar to inversion within a chromosome, especially if nucleotide sequence and pattern are still identified with protein specificity and ultimately with gene action. Similarly, the double break α_1 - α_2 would result in two fragments, which if they linked up with others would give an effect analogous to chromosomal interchange. Further, if the breaks α_3 and α_5 occurred in conjunction with hydrogen bond rupture (γ), as during γ -irradiation, the segment α_3 - α_5 would be lost and the replication of this section

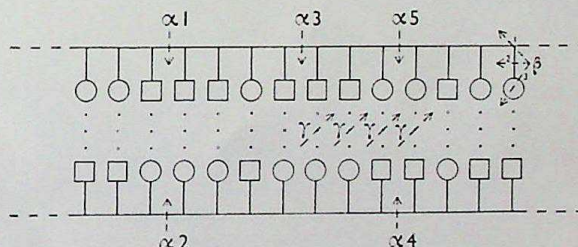


FIGURE 3 - Possible modifications of the deoxyribonucleate molecule (depicted schematically as in figure 2). -- $\rightarrow$ Possible breaks. α , Breaks in the main-chain phospho-ester linkages. β , Breaks in other covalent bonds of the nucleotide units. γ , Rupture of the cross-linking hydrogen bonds (see IX and X).

would be impaired: this could be part of the molecular basis for mutations. At present, however, these constitute formal analogies only, because of the disparity of scale between chromosomes and the DNA molecules.

(b) Other covalent bonds might be destroyed (e.g. $\beta_1, \beta_2, \beta_3$, figure 3), but usually by treatment under conditions which are probably less important biologically.

(c) The rupture of cross-linking hydrogen bonds (γ , figure 3), usually called 'denaturation' because it leads to permanent loss of the helical configuration, can be caused by ultrasonic irradiation, by ionizing radiation, by heat, by solutions of high or low pH , and presumably by enzymes [25]. In the

case of heating and ionization it seems [26] that a minimum sequence of ten or more hydrogen bonds has to be ruptured before permanent denaturation occurs (as γ , figure 3). Hydrogen bond rupture is one of the first detectable effects of γ -rays [12c] on DNA in solution and must cause a loss of the double helical form in various sections, thereby perhaps impairing its ability to replicate.

Although these analogies between chemical and biological behaviour are encouraging, it is not possible to go any further at present because of our ignorance concerning the arrangement of the DNA molecules in the chromosomes [18]. The diameter of a single DNA molecule is 18 Å, and that of the simplest nucleoprotein is only slightly more than this [20], whereas the next nearest units of chromosome architecture seem to be the particles (4000 Å long by 400 Å wide) isolated by D. Mazia [27], or the 'microfibrils' of 100–200 Å diameter observed in the electron microscope [18]. Such units could contain many DNA molecules: Wilkins [28] has reported X-ray evidence for a regular array in fowl erythrocyte nuclei of parallel nucleohistone molecules of 20 Å diameter and 45 Å apart. Since DNA molecules, as isolated,

usually have a length along the axis of the order of 30 000 Å (for a molecular weight of about six million), which is sometimes very much greater than the largest dimensions of the biological structures from which they are derived, it has been proposed [18] that at certain points the DNA molecule can fold back on itself. This is feasible if there is an occasional internucleotide break (α).

The double helical structure of the DNA molecule can now perhaps be identified with the 'molecular spirals' long postulated as the basis of the visible chromosome spirals [29]. S. Benzer [30] has recently shown that it is possible to obtain recombination between very closely linked sites on the genetical chromosome of a bacteriophage which, if the physical chromosome were DNA, would correspond to a separation of only about a dozen nucleotides, and thus the gulf between the molecular and cytological levels of organization may eventually be bridged.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the permission given by Professor J. T. Randall, F.R.S., Dr M. H. F. Wilkins, and Dr W. E. Seeds to prepare and publish figure 1.

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Plant virus diseases and their identification

R. MARKHAM

While it is difficult to assess the relative economic importance of the various types of disease agents in plants, there is little doubt that the attention paid to the viruses is much less than it should be. This is because they are rather difficult to handle experimentally, and the symptoms which they produce in plants are not familiar even to many plant pathologists, and so are often overlooked or thought to be due to mineral deficiencies or fungal diseases.

The range of plants susceptible to virus infection is very great, and one may expect to find at least one virus disease of any flowering plant, though oddly enough the conifers and lower plants do not appear to be susceptible to virus diseases. The number of viruses affecting plants is also great; the known number is now in the hundreds and increasing all the time. Many viruses are extremely catholic in their choice of host, infecting species of both monocotyledons and dicotyledons. Most viruses, it is true, tend to have a somewhat more restricted host range, but it is exceptional for a virus to infect only one species of plant, and this is one of the more insidious characteristics of this type of parasite. It is unusual for a plant either to recover from virus infection or to die because of it, with the result that sources of infection tend to increase in numbers, especially when the host plants are perennial and are propagated by vegetative means, as are, for example, potatoes and many garden plants.

THE NOMENCLATURE OF PLANT VIRUSES

Most plant viruses have trivial names, derived from the symptoms exhibited by the host on which the virus was originally found. The use of this type of nomenclature, based as it is on historical accident, is frequently a cause of confusion. For example, one of the more widespread and important virus diseases in Great Britain is called cucumber mosaic (figure 8), but the cucumber (*Cucumis sativus*), being a tender and exotic plant, is quite obviously incapable of being the primary host of an obligate parasite like this virus, which actually has an immense host range (figures 2, 4, 7, 9-11). This range includes many hardy perennials such as *Chrysanthemum*, *Daphne*, and *Euonymus*, from which the virus is spread by migrating aphids, the natural vectors of this disease.

An interesting example of the confusion that this type of nomenclature may cause is seen in the

disease known as tobacco necrosis. This disease was originally observed many years ago in Cambridge, when tobacco plants (*Nicotiana tabacum*) which were being used for experimental purposes were inoculated with sap pressed out from their own roots. A characteristic disease developed (figure 13), and the virus was found to cause similar symptoms on a large number of plants, in none of which was it able to produce symptoms other than local ones. This virus, or, as it was later found to be, group of viruses, was studied for years as an academic curiosity. Some seven years ago, however, it was found to be causing a serious disease of french beans (*Phaseolus vulgaris*) in Holland, from which country tulips (*Tulipa* sp.) also having this virus have been imported into Britain (figure 14). It is also now frequently found in plants of *Primula obconica*, which have become infected by being raised in contaminated soil. This virus is unusual in being transmitted in this way, and the original infections presumably arose from inadequately sterilized potting-soil.

PLANT VIRUS SYMPTOMS

Flower 'breaking'. The most obvious, and certainly the least unattractive, symptoms caused by viruses are the flower breaks. In these, virus infection causes characteristic alteration of the pigmentation of the flower petals. The reddish and bluish colours of flowers are due to anthocyanin pigments, and most flower breaks affect these pigments. The best-known example of this is to be found in tulips, which are subject to a specific virus which causes the flower colour to break (figure 1). In tulips, as in other plants, such as the wallflower (*Cheiranthus*), a blood-red or orange-red colour is usually due to an anthocyanin pigment superimposed on carotenoid pigments, and it is unusual for the latter to be affected. In this case one gets a break with a yellow background, such as is caused in the wallflower (figure 3) by the



FIGURE 1 - Tulips showing flower break caused by the specific tulip breaking virus.



FIGURE 2 - Viola tricolor showing a flower break due to cucumber mosaic virus.



FIGURE 3 - Wallflowers infected with cabbage black ringspot virus. Healthy flowers are shown on right.



FIGURE 4 - Flower break in Campanula isophylla infected with cucumber mosaic and another virus.

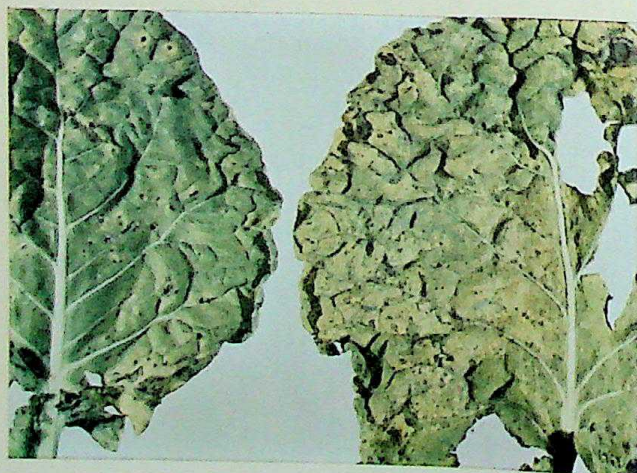


FIGURE 5 - Brussels sprouts plants infected with cabbage black ringspot virus.



FIGURE 6 - Flower break of sweet pea caused by the pea mosaic virus.

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FIGURE 7 - A flower break, frequently found in *Gladiolus*, due to cucumber mosaic virus.



FIGURE 8 - Cucumber mosaic virus on cucumber.



FIGURE 9 - Larkspur, showing flower breaking caused by cucumber mosaic virus.



FIGURE 10 - Symptoms of cucumber mosaic virus on tomato. Note the reduction of leaf lamina and the distortion of the flowers.

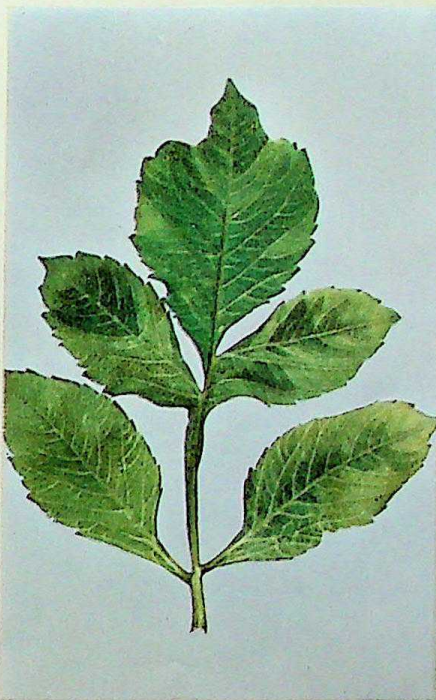


FIGURE 11 - Dahlia showing symptoms of infection with cucumber mosaic virus.

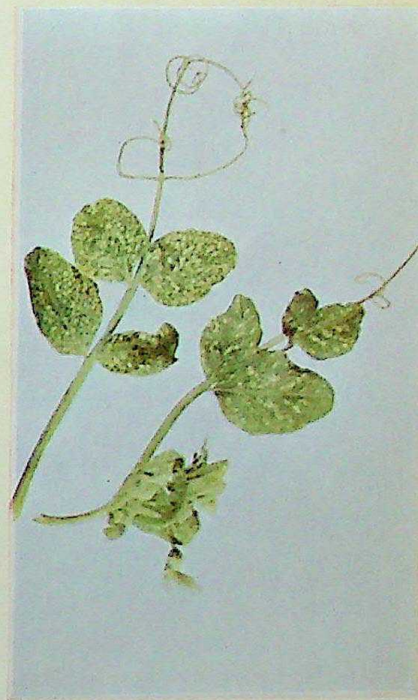


FIGURE 12 - Pea mosaic virus. This is one of the few seed-transmitted virus diseases.



FIGURE 13 - Lesions of tobacco necrosis virus on tobacco.



FIGURE 14 - Necrotic symptoms on tulip, now known to be due to tobacco necrosis virus.



FIGURE 15 - Sugar beet yellow virus, economically a very important disease of sugar beet.



FIGURE 16 - Tumour or enation on the underside of a cucumber leaf, caused by tomato blackring virus.

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FIGURE 17 - *Tomato spotted wilt virus* on tomato, showing ringspotting and bronzing.



FIGURE 18 - A ring-shaped lesion on a tomato fruit due to the tomato spotted wilt virus.



FIGURE 19 - Underside of a potato leaf, showing typical primary symptoms of potato Y virus. These are often mistaken for those of blight (figure 20).

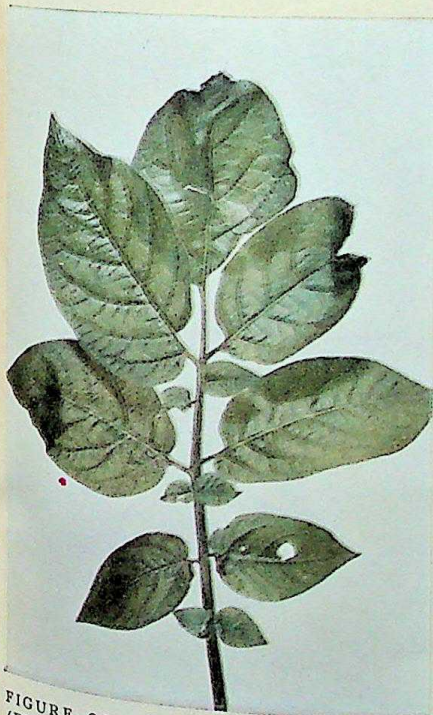


FIGURE 20 - Potato leaf showing blight (*Phytophthora*) lesions.



FIGURE 21 - Typical symptoms of cabbage black ringspot virus on tobacco, which is used as a test plant for this virus.



FIGURE 22 - Local lesions of tobacco mosaic virus on *Nicotiana glutinosa*. These may be used for quantitative assay.

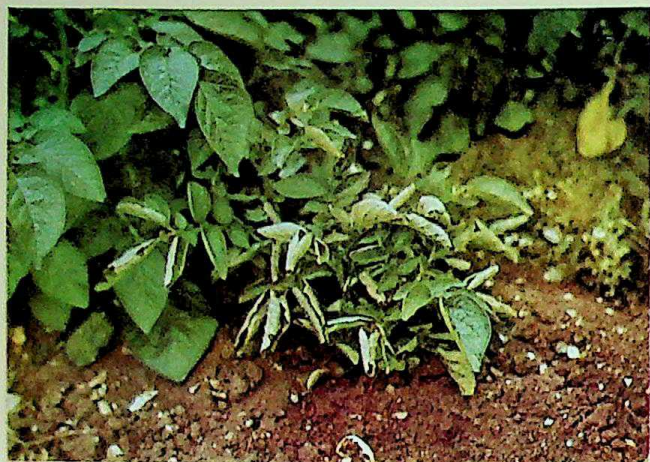


FIGURE 23 - *Potato leaf-roll virus*. This very severe virus infection is common in the south of England and is spread by aphids, as are many plant viruses.

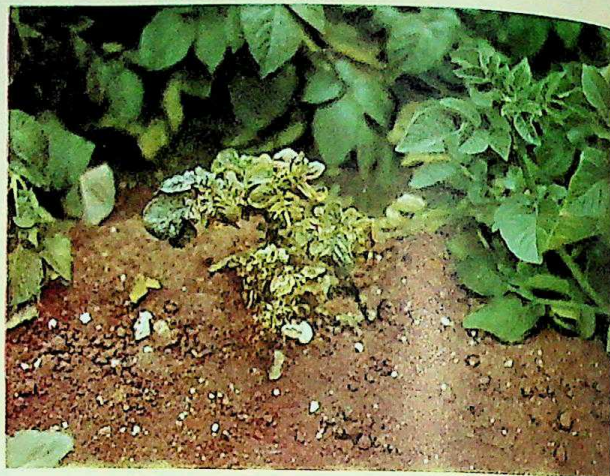


FIGURE 24 - *Curly dwarf*, a disease of potato caused by chronic infection with potato viruses X and Y.



FIGURE 25 - *Potato virus X* on tobacco, which is one of the best test plants for diagnosing this disease. The symptoms develop about a fortnight after inoculation.

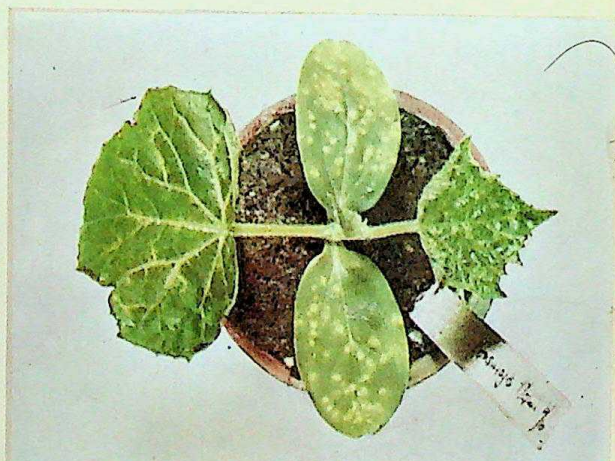


FIGURE 26 - Local lesions and systemic mosaic of cucumber inoculated from a South American potato plant.



FIGURE 27 - *Turnip yellow mosaic* causing an extremely brilliant mosaic on *Brassica sinensis*.

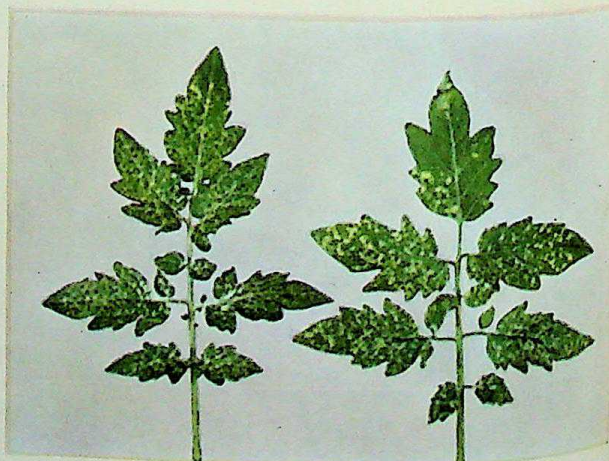


FIGURE 28 - *Aucuba mosaic* of tomato. This is caused by a strain of the tobacco mosaic virus.

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cabbage black ringspot virus; this virus is very common in brassica crops (figure 5), in which the symptoms might easily be taken as being due to mineral deficiency.

Occasionally, colour breaking affects only part of the anthocyanin pigmentation, and one may then get multicolour effects as in pansy (*Viola tricolor*, figure 2) and in larkspur (*Delphinium* sp. figure 9). These two colour breaks are caused by the cucumber mosaic virus, as are breaks of many other plants, such as *Gladiolus* (figure 7), *Anemone*, etc. These quite obvious symptoms are so infrequently recognized that the break in larkspur, for example, has been investigated under the impression that it was a genetic character, while a superficial examination of flowering plants in nurseries suggests that many 'varieties' are in fact merely normal plants showing disease symptoms.

The physiology of flower breaking is a subject that would well repay investigation, and it is interesting that a virus which causes breaks in one plant will not necessarily cause them in another having the same anthocyanin pigments. Thus cucumber mosaic virus, although extremely common in *Dahlia*, never causes its flowers to break.

Another common flower break is that of the sweet pea (*Lathyrus odoratus*, figure 6), which is caused by pea (or bean) mosaic virus (figure 12). This virus causes serious diseases of peas (*Pisum sativum*) and beans (*Vicia faba*), and is all the more serious because, unlike most viruses, it is quite frequently carried through the seed, as well as being spread by aphids. Seed transmission also occurs quite commonly in the case of lettuce mosaic virus, but in most plants some kind of physiological barrier prevents infection of the seeds, which thus give rise to healthy plants.

OTHER TYPICAL PLANT VIRUS DISEASE SYMPTOMS

Mosaics. One of the commonest symptoms is the mosaic, a typical example of which in *Dahlia* is shown in figure 11. This particular mosaic is caused by the cucumber mosaic virus. Other mosaic symptoms are shown in figures 8, 12, and 25-28. Mosaics are caused by variations in the chlorophyll content of various parts of the leaves, and may range from a scarcely visible mottle to a brilliant variegation such as is given by dandelion (*Taraxacum*) yellows virus and turnip yellow mosaic virus in Chinese cabbage (*Brassica sinensis*), both of which might be mistaken for genetic variations.

Malformations. While most mosaics are accompanied by slight leaf malformations, some extreme

cases are to be found. Figure 10 shows the typical symptoms of cucumber mosaic virus on the tomato, an appearance which sometimes leads growers to imagine that the leaves have been eaten away by insects. Such symptoms may also be caused by a strain of tobacco mosaic virus, and a somewhat similar effect may be produced by the accidental application of selective weedkillers.

Another type of malformation is the enation, which is a tumour of leaf tissue: a good example of this may be seen on a cucumber leaf (figure 16), due to the tomato blackring virus. An unusual feature of this virus is that it causes the formation of enations only of glasshouse cucumbers, and not of the outdoor, or ridge, varieties.

Yellowing. The symptoms of yellowing of the leaves are to be found in Britain in two important virus diseases, sugar beet yellows (figure 15) and potato leaf-roll (figure 23), and they differ from mosaics in that the lack of chlorophyll is not defined as blotches. These diseases cause damage to the vascular system of the plant, and they are characterized by the leaves becoming leathery in consistency, with a tendency to pigmentation. Potato leaf-roll is fairly characteristic but may be confused with symptoms due to injury of the stem, while sugar beet yellows is easily mistaken for symptoms of mineral deficiency.

Ringspots and necrosis. Many viruses tend to cause the formation of rings on their hosts, and a particularly characteristic ring is shown in figure 18, which shows the effect of tomato spotted wilt virus on the fruit of tomato. This virus also causes the formation of rings on a large number of plant leaves, including those of tomato (figure 17), in which it also causes the production of anthocyanins, which make the leaves turn bronze. Other symptoms of the ringspot type are to be seen in figures 13, 21, 22, and 26, which show local symptoms on artificially inoculated leaves, and in figure 5, which shows the results of a systemic infection.

Ringspots may be purely chlorotic, but are very frequently necrotic. If the necrosis is very severe it kills the infected cells and so cuts the virus off from the healthy tissues. This is shown in figures 13 and 22. If the necrosis is less severe locally, the net effect on the plant is worse. Figure 19 shows the primary symptoms of potato Y virus on potato, which may be confused with potato blight (*Phytophthora*) infection (figure 20). Close examination of the underside of the leaf, however, shows that the necrosis is confined to the veins, down which it progresses, after which the leaves collapse and

hang down. Chronic infection with this virus together with the potato X virus causes an extremely severe stunting of the potato (figure 24).

METHODS OF IDENTIFICATION

It will be evident, from the description of the various symptoms caused by plant viruses in their hosts, that the actual diagnosis of plant virus diseases is not altogether straightforward. The identification of a virus disease by the symptoms shown on any host plant is more of an art than a science, and while it is possible to become expert by practice, it is usually desirable to confirm one's diagnosis experimentally. Fortunately this is generally quite easy, it being sufficient to make a few inoculations of appropriate indicator plants whose reactions to particular viruses are well known. For example, the virus causing the break in wallflower may be identified by the symptoms that it causes in tobacco. A small part of the wallflower plant is ground up, the juice is rubbed gently over the leaves of a tobacco plant, and excess is washed off with water. In a few days, characteristic reddish lesions, having a chlorotic boundary, develop on the plant (figure 21).

The tobacco plant is a very useful test plant. Thus figure 25 shows the effect of potato X virus in a tobacco plant, which was inoculated from a potato plant which did not show any visible disease. The mild strains of potato X virus may not cause obvious 'local' lesions on the inoculated leaves of tobacco, and the leaf illustrated is in fact one of the younger leaves which has developed the systemic symptoms of the disease. This type of symptom takes about a fortnight to develop.

Another plant which is used very frequently as a test plant is *Nicotiana glutinosa*, and figure 22 shows the symptoms caused in this plant by strains of the tobacco mosaic virus. This virus is extremely common in tomato plants, largely owing to the habit of smoking; commercial tomato houses are usually heavily contaminated with the virus, strains of which have adapted themselves very well to the tomato. Many tomato growers, nevertheless, do not realise that their tomato plants are diseased. Figure 28 shows the

symptoms due to a more obvious strain of this virus, known as tomato aucuba mosaic virus because the symptom that it causes is a brilliant yellow mottle, rather like that found on the leaves of the Japanese variegated laurel, *Aucuba japonica*.

Very frequently plants are found simultaneously infected with two or more viruses. For example, the virus shown in figure 16 came originally from a tomato fruit having three different viruses, and the *Campanula* in figure 4 had two viruses, as did the potato plant in figure 24. Separation of mixtures such as these is difficult, but may be accomplished by taking advantage of the different host ranges of the various viruses involved. Figure 26 shows one such separation. This virus came from a South American potato, and had the property, unusual for a potato virus, of causing a disease in cucumber. Transfer to the latter plant, therefore, automatically separated it from a number of other potato viruses. Other methods for separating complexes of viruses involve the stability of individual viruses to heating or ageing. Thus sap from the potato in figure 24, which has two viruses in it, will lose one (virus Y) on standing for a few days, leaving the stable virus X. Virus Y may be isolated by transmitting it from the original plant to another potato plant or to a tobacco plant, by means of an aphid, such as *Myzus persicae*, which does not transmit virus X.

Other methods of identification, which have limited use, include serological reactions using the serum from rabbits immunized towards the virus in question. In this method the rabbits do not develop any disease, but they produce antibodies which react specifically with sap from diseased plants. Unfortunately few plant viruses are present in sufficient concentration to react in this way.

Finally, a small number of viruses are sufficiently stable, and are present in such high concentration, that one can actually effect the identification by purifying the virus and examining its crystals under the microscope. Turnip yellow mosaic virus (figure 27) is one such virus; as it may be crystallized in a few hours, this method of identification is both certain and rapid.

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This year marks the 250th anniversary of the birth of Linnaeus, an outstanding figure in the history of biology. This article includes a short biographical sketch—from which he emerges as a somewhat complex personality—but is rather more concerned with an assessment of the value and significance of the Linnaean system. While this had defects, notably its wholly artificial nature, it did at least bring order to the vast amount of descriptive information about plants which had been accumulated by the eighteenth century.

Linnaeus laid it down in his medical teaching that the first step towards health and happiness is to be born of young and vigorous parents in their full tide of sexual ardour: this advantage he considered himself to possess. His father, Nils, was perpetual curate of Stenbrohult in southern Sweden. On 6th March 1706, at the age of 32, he married the rector's daughter, and on 23rd May (NS) 1707 Carl Linnaeus was born. Close affection lasted for life between both parents and their firstborn.

Nils was unable, when the time came, to maintain his son for long at a university, but in a way he did even better. He endowed him with a nature that inspired such confidence and liking that a succession of wealthy and influential patrons made it possible for Carl to follow wherever his abilities and inclinations should lead. At Lund, at Uppsala, in Stockholm, and abroad in Holland, there was, at least intermittently, manna from heaven.

In his second year at Uppsala (1729–30) Linnaeus delivered a New Year's gift to his current benefactor in the form of a little tract *sponsaliorum plantarum*, which gave the first taste of his quality. Olof Rudbeck the younger, reluctantly responsible for the botanical teaching in the university and wanting to devote himself to other things, thereupon arranged for his gifted student to take over his lectures, and the attendances rose rapidly from eighty to four hundred. Even earlier than this, Linnaeus had been making a small income by private teaching.

Two years later he undertook a journey to Lappland, a prototype of the journeys made nowadays by members of undergraduate exploration clubs, but with one major difference. The offices of organiser, mineralogist, botanist, and zoologist were all filled by Carl Linnaeus: it was a one-man expedition. He applied to the Royal Society of Science in Uppsala for a grant of four hundred dalers towards an estimated requirement of six hundred; after some hesitation the grant was made,

leaving, it is said, only one daler nineteen öre in the Society's coffers. The journey was attended with some danger and a good deal of hardship, which the young explorer saw no reason to minimize in his published diary. As he and his Lapp guide struggled across the Lycksele fells 'sometimes we came where no bottom was to be felt, and we were obliged to measure back our weary steps. Our half boots were filled with the coldest water . . . Had our sufferings been inflicted as a capital punishment, they would even in that case, have been cruel, what then had we to complain of? I wished I had never undertaken my journey.' But in the event he returned home fitter than he set out, and declared himself able to walk four times farther. Scientific results were enshrined in the *Flora Lapponica* and in a still very readable diary.¹

After he had been seven years a student and no other prospect had appeared, Linnaeus decided he would have to earn a living as a practising physician. The Swedish fashion then was to qualify with a Dutch Doctorate of Medicine, and for this purpose he travelled to Harderwijk, which had a university much frequented by foreigners seeking medical degrees. He arrived on 18th June (NS) 1735 and received his degree, licensing him to practise, a week later.

In spite of this promptness, he already lacked funds to pay for his return to Sweden, and his second object in coming to Holland, the publication of the works he had prepared in Uppsala, was still unaccomplished. Again wealthy amateurs came to his help. He remained two and a half years, and during this time many of his most important books were published.

In the middle of his stay he made an excursion to England to see the collections of Sir Hans Sloane and the botanic gardens at Chelsea and

¹ Translated into lively English in 1811 by Sir James (Edward) Smith, first President of the Linnaean Society, under the title *Lachesis Lapponica*.



FIGURE 1 – Wedgwood portrait medallion of Linnaeus based on the original by C. F. Inlander. Solander, who sailed with Captain Cook in the Endeavour and who was a pupil of Linnaeus, pronounced one of these medallions 'to be the best likeness of his old master that was ever executed'.

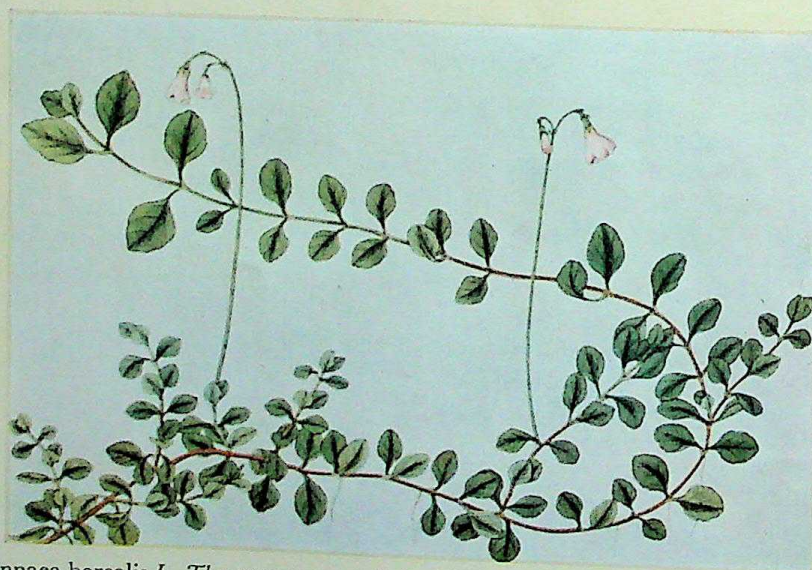
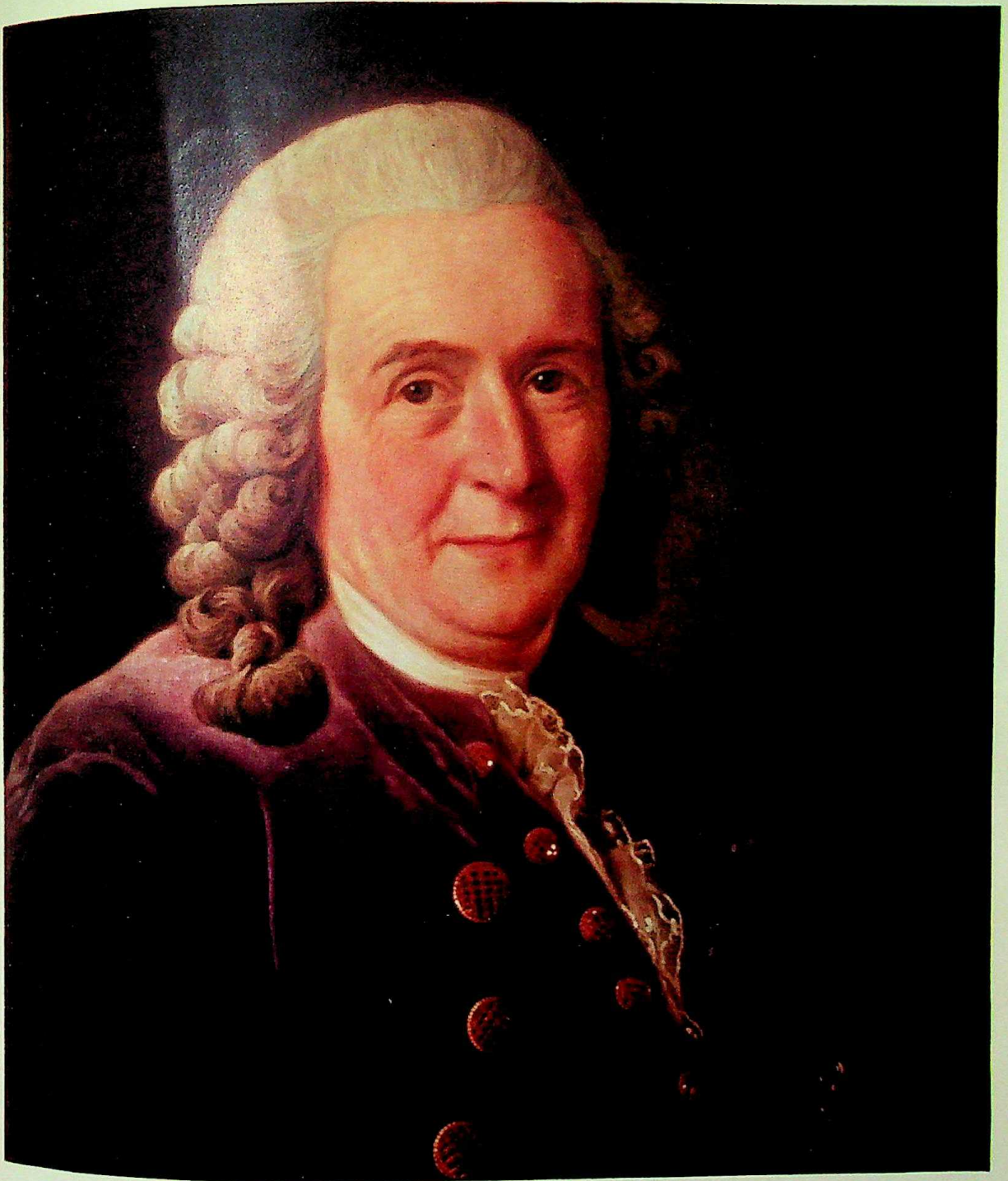


FIGURE 2 – *Linnaea borealis* L. The genus was named after Linnaeus by his friend Gronovius in Holland, and is the basis of the decoration on a tea service preserved in the museum of the Botanic Garden at Uppsala.

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Carl - Linné

FIGURE 3 - Linnaeus at the age of 68. Portrait in oils by A. Roslin, in the collection at Gripsholm. The signature is ten years earlier.

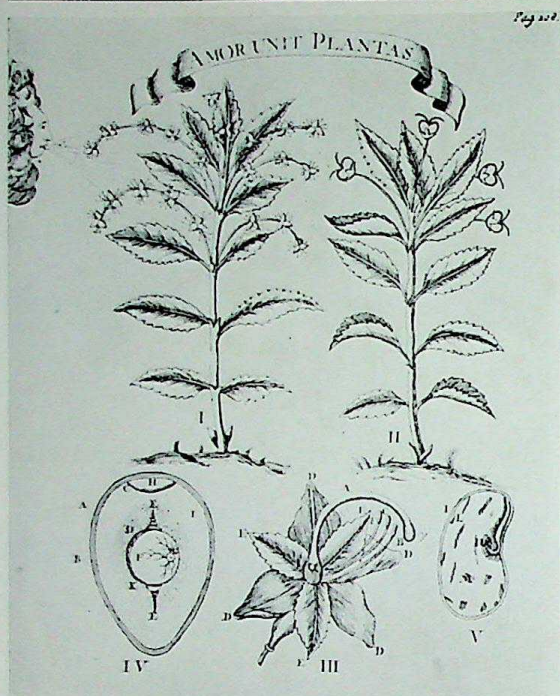


FIGURE 4—The diagram used to illustrate the Linnaean conception of the sexuality of plants published in the first volume of the *Amoenitates Academicæ* in 1749. I and II illustrate pollination by wind; IV and V, his misleading comparison between a seed and an egg.

Oxford. Philip Miller at Chelsea and J. J. Dillenius at Oxford received him coolly, but soon succumbed to his enthusiasm and charm. The

English as a whole did not impress him favourably; he later wrote 'little do I love the race', and said that Dillenius, born in Darmstadt, was the only real botanist among them.

Linnaeus returned to Sweden in 1738 by way of Brussels and Paris, and set up as practising physician in Stockholm. After a slow start, he gained patients in court circles and a lasting connection with Count Tessin, head of the Hats party in the Riksdag. Through the latter's influence Linnaeus was put in the way of remunerative jobs, received the title of *Archiatr* (royal physician), and was later (1753) made Knight of the Polar Star. He also became first president of the Academy of Science.

At the age of thirty-four Linnaeus was appointed a professor of medicine and botany at Uppsala and rejoiced at being 'freed from the wretched practice in Stockholm'. He was henceforward able to teach, collect, and investigate plants according to his fancy. He was an enthusiastic cultivator—another inheritance from his father—and developed the botanic garden until it was comparable with those he had seen abroad; during a period of emergency he even acted as his own head gardener. He was allowed to build an orangery and an official house, and bought himself a country estate at Hammarby where he lived in patriarchal style with his family, visited by students and foreigners. During the earlier years of his professorship he travelled about Sweden on government commission; but after 1749 he limited himself to a series

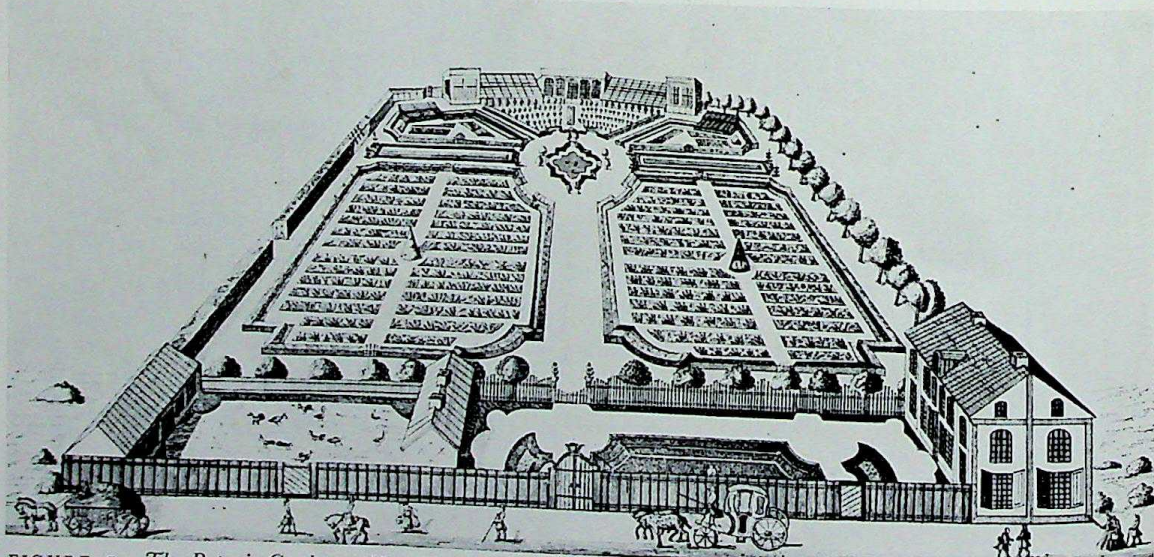


FIGURE 5—The Botanic Garden at Uppsala in 1749, from a contemporary engraving. The orangery encloses the far end and Linnaeus's official house stands in the right foreground. Much of the original layout has been restored, and the house is now a museum of personal relics of Linnaeus.

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of set excursions around Uppsala with his students. These were highly popular outings, often attended by two or three hundred people.

Flags flying, French horns blowing, kettle-drums throbbing,
And Carl Linnaeus marching at their head.

.....

And, afterwards, each with his own flower-fettered girl,
They'd dance the rest of the summer night away,
though the girls may be mostly authorized by Alfred Noyes' poetic licence.

Carl Linnaeus was a complex, highly self-conscious personality. At various times he wrote at least four autobiographical sketches, and a *philosophia humana* which is not inspiring. He also wrote a *Nemesis Divina*, ostensibly for the guidance of his son, who was said to care 'not so much for Flora as for the nymphs'; and it may be true that 'no man listened more than he to the tolling of death's bell'. He was still in the twenties when he asked, in a technical communication on botany, 'What do mortals more desire in this unsubstantial fleeting world than that . . . when our feeble frame decays and after death becomes noisome, some honourable remembrance of their names, however slight, should reach posterity, and endure yet a few days?'

Everything about himself he put on paper for others to read. He had the modesty of assured position, but also the complacency of achievement. He could write '*Linnaea* . . . lowly, insignificant, disregarded, flowering but for a brief space—from Linnaeus who resembles it'; but also 'I have been the greatest reformer in that science (botany) that ever existed'. Like Caesar, he commonly wrote of himself in the third person. He became a nabob of science and conferred the honour of a generic name upon a contemporary (*Rudbeckia*, *Dillenia*, and many others) with scarcely less sense of favour than the king ennobled his own to von Linné.

Some have elevated Linnaeus to the status of moral as well as natural philosopher, and have claimed for his idiosyncratic mixtures of Swedish and Latin a place in literature. English readers can best judge his discursive style in the very elegant translation of *Critica Botanica* made by Sir Arthur Hort.

But it was his service to biological taxonomy that was his contribution to human knowledge, and for this he had three outstanding assets: a tidy mind, the gift of clear verbal description, and a complete and utter belief in the value of what he

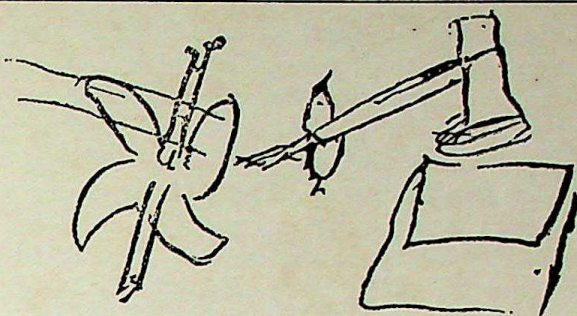


FIGURE 6—Sketch from Linnaeus's *Lappland diary*. 'In every river a wheel is placed contrived to lift up a hammer for the purpose of bruising flax'. Linnaeus's pencil did little to help his pen.

was doing. He was, in his own words, a born methodizer; and he was the first to achieve critical diagnoses of plant and animal species in place of somewhat rambling or unmethodical descriptions. But the third asset was perhaps the most potent: never did he doubt the wisdom of spending life, health, and means in perfecting a Linnaean system of nature. All through life he worked with a fury that may have prematurely broken down his strength; he believed himself that it did, and his last decade was overshadowed by progressive ill-health.

His contemporaries accepted his own estimate that he had wrought a revolution, but there were really many indications of the coming change. To some extent he has benefited by the tendency of big reputations to absorb small ones, a process he even seems to have done something to assist.

The binomial system of employing a latinesque generic noun followed by a specific adjective was used systematically for the first time by Linnaeus, though he did not, in fact, use it consistently until 1753, when most of his work was already done, and Caspar Bauhin (1560-1624) had listed many binomials in his *Pinax* a century earlier. Linnaeus's greatest contribution to nomenclature was more fundamental.

In an age of poor communications and no co-ordination, a fearful synonymy had inevitably entangled natural history, and the more industriously the collectors, the botanists, and the zoologists worked, the worse this grew. Many names could all too easily be attached to a single species, and there was not even agreement about how a name should be arrived at, nor what names were suitable and what were not. Linnaeus laid down the required system in a long series of maxims varying from the weighty to the trivial, and he got others to accept it, even though it often meant sweeping aside much of their own work. His

aphorisms are still the firm foundation of the modern international rules of biological nomenclature, and they, rather than the binomials, are his true memorial.

The idea of classification cannot be considered any one man's discovery. The seventeenth-century naturalists instinctively grouped together species that resembled one another. The more numerous the points of resemblance the more natural, in the sense of formal logic, was the grouping. But, though many such groups were apparent, the whole range of living things obstinately refused to divide itself in any orderly way among them. Early attempts at arrangement aimed at a natural system, but came more and more to rely on arbitrarily chosen single characters. As a result, they were partly natural, but to a much larger extent artificial.

The arrangement of plants proposed by Joseph Pitton de Tournefort (1656-1708), at first used by Linnaeus, rested mainly on the characters of the floral envelope and involved many difficulties. The Linnaean system, based solely on the sexual organs, was more—indeed, completely—artificial. As a means to classification the styles and stamens had no deeper significance than the petals, but they had far greater convenience; the only qualification needed for placing plants in the Linnaean system was the ability to count up to twenty. It became a favourite occupation of Young Ladies.

Linnaeus was probably the first to realize clearly that a natural classification could not be achieved by artificial means and to make a deliberate

choice: he chose an empirical system because a rational one was out of his reach. He explicitly stated the need for continuing the struggle and made suggestions for this where they seemed possible. An entirely natural classification of flowering plants, for example, is still a desideratum. In defence of Linnaeus it may also be said that the temporary acceptance of formalism gave taxonomy a badly needed breathing-space and, further, that the idea of natural classification did not then carry the overriding importance that evolution gave it a hundred years later. He considered the problem of origins, but he made nothing of it.

Linnaeus tidied up the mess of an era and so cleared the way for its successor; but he made little contribution to the new age. Though Hooke, Malpighi, and Grew had shown the way, he rarely used a microscope and then not always with fortunate results. As to the real nature of organisms, their intimate structures, and their physiology, he seems to have had little curiosity.

In the year of Linnaeus's death Gilbert White enlarged on the theme that the botanist 'should be by no means content with a list of names: he should study plants philosophically, should investigate the laws of vegetation'. For many years, however, most botanists were satisfied to sun themselves in the *pax Linnaea*. By his very success he put botany into a strait jacket from which it with difficulty freed itself in a century. But to blame Linnaeus for this, would be to visit the iniquity of the children upon the father.

Book reviews

ALCHEMY

Alchemy, by E. J. Holmyard. Pp. 281. Penguin Books Limited, Harmondsworth. 1957. 3s. 6d. net.

It would be difficult to find a better qualified expositor of alchemy than Dr Holmyard. With equal appropriateness, this book, being one of a numerous brood of Pelicans, bears the symbol of that devoted bird, the alchemical pelican, on its cover. In its fullest aspect alchemy is a subject so complex and tangled, and extending over so long a period in human history, that a complete treatment in a volume of this size would be out of the question. The author has therefore wisely concentrated on exoteric alchemy. In contrast to esoteric or mystical alchemy,

this was concerned mainly with practical ideas and experiments aimed at producing the hypothetical philosopher's stone and the consequent achievement of transmutation or multiplication, otherwise the artificial making of gold and the related elixir of life. He has covered this field, within the ambit of a dozen chapters, with his accustomed fluency and thoroughness. He writes, of course, with particular force and authority in his earlier chapters on Greek and Islamic alchemy: this part of the book in particular will be appreciated and valued by the expert and scholar even more than by the lay reader. For the specialist a closer documentation would have added to the worth of an illuminating treatise.

Besides some text figures, the book contains an excellent selection of thirty-six nicely produced illustrative plates. The publishers, themselves notable exponents of the art of multiplication, have combined with the author in producing a very attractive and useful volume.

J. READ

THEORY OF STATISTICS

Statistical Methods and Scientific Inference, by Sir Ronald Fisher. Pp. viii + 175. Oliver and Boyd, Edinburgh. 1956. 16s. net.

Sir Ronald Fisher has long been the leading figure in the development of a theory of scientific inference from statistical information; even the most active

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in exploring alternative lines of reasoning have owed much to his pioneering thought. Yet any student of Fisher's theory is obliged to read papers published over a period of 35 years, with the consequent difficulty of making allowance for changes in emphasis as Fisher's own mastery has grown.

Statisticians will welcome this distillation of the earlier papers: principles are unaltered, but an illuminating and characteristically Fisherian presentation relates them to modern statistical practice. Fisher emphasizes the difference between inference appropriate to scientific research and that needed in acceptance and decision techniques, and shows with remarkable clarity the nature of likelihood and the fiducial argument. One example illustrates especially well the role of ancillary statistics. The last two chapters require mathematical sophistication in the reader, but every experimental scientist could profitably study the first four. For some, the necessity of referring to the early papers will remain, but that task will be greatly eased by a discussion dated 1956. Only some unhappily phrased personal comments mar a great book that will consolidate present ideas and stimulate many advances in statistical theory and practice.

D. J. FINNEY

MATHEMATICS OF DIFFUSION

The Mathematics of Diffusion, by J. Crank. Pp. vi + 347. Clarendon Press, Oxford; Cumberlege, London. 1956. 50s. net.

This book is not concerned with the molecular theory of diffusion, and, as Dr Crank remarks in his preface, a more precise title would be 'Mathematical solutions of the diffusion equation'. The subject has a long history and perhaps some may think it is played out; in reality, there have been important developments in recent years and the present account is opportune.

The first six chapters deal with solutions of Fick's equations with constant diffusion coefficient for various boundary conditions; the Laplace transform is extensively used as well as the older methods. More complicated problems, such as diffusion with a moving boundary, simultaneous diffusion and chemical reaction, and systems with variable diffusion coefficients, are discussed in considerable detail in later chapters. The final chapter deals with the simultaneous diffusion of heat and moisture; problems of thermal diffusion or simul-

taneous diffusion of two solutes with interacting fluxes are not, however, considered.

All those interested in diffusion problems should find the book of value; the treatment of problems involving variable diffusion coefficients, in particular, provides a most useful account of recent work on this topic, and the earlier chapters give an unusually clear and well-balanced summary of the more 'classical' part of the subject.

J. N. AGAR

QUANTUM PHYSICS

Quantum Field Theory, by H. Umezawa. Pp. xiv + 364. North-Holland Publishing Company, Amsterdam. 1956. 70s. net.

This is a highly formal approach to a highly formal subject, and although we are told—and it is true—that the book starts from first beginnings, it is not for the beginner. A fair knowledge of group theory and the special theory of relativity is presupposed; but this is no adverse criticism, since the overloading of books with extraneous matter is a tendency to be strongly resisted in this age of high prices.

By most resolute pruning, the author has succeeded in providing a really comprehensive treatise in a comparatively small compass, and in particular the account of the relativistic wave equation, which occupies the first hundred pages, is masterly. After that, more attention to physics in describing field theory proper would have enlivened the somewhat dry mathematical pages. A more serious fault is that results sometimes appear stated rather than proved; for example, equation (8.6).

This reviewer strongly approves of positons and negatons. But why 'proper field', when 'self field' (used once) is a much more expressive as well as a firmly established term? However, these are small matters in an excellent work, which should remain a standard treatise for many years. L. R. B. ELTON

NUCLEAR SCIENCE

Annual Review of Nuclear Science, Vol. V, edited by James G. Beckerley. Pp. ix + 448. Annual Reviews Inc., Stanford, California. 1955. \$7 net.

Here again is the by now well tried mixture of pure and applied physics, radiochemistry, and biology. This series now follows an accepted pattern, and general remarks made about previous volumes apply equally to the present one.

Much knowledge has accumulated of late about nuclear structure, and three articles deal in different ways with this subject. Accounts of the instruments of nuclear physics include the bubble chamber for the first time, as well as the nuclear reactor as a research tool. Surprisingly, there is no mention of fundamental particles—this has not happened before in this series. The speed of advance of nuclear physics is indicated by the fact that after this pause the past year has produced the anti-proton, the neutrino, and the anti-neutron.

The articles are becoming increasingly specialized, and the physicist is soon out of his depth among the chemists and biologists. The article on 'Removal of radio-elements from the mammalian body', however, deserves to be widely read, for behind the account of experiments on rats hide the horrors of war.

L. R. B. ELTON

NUCLEAR PHYSICS

Progress in Nuclear Energy, Series I: Physics and Mathematics, Vol. 1, edited by R. A. Charpie, J. Horowitz, D. J. Hughes, and D. J. Littler. Pp. x + 398. Pergamon Press Limited, London. 1956. 84s. net.

The original impetus to this new series of reviews on nuclear science, of which this is the first volume to appear, was provided by the Geneva Conference. The proceedings of this conference have already appeared in print; in this series they are reviewed and critically evaluated. This in itself is a laudable task, but whether it justifies the whole apparatus of a new and truly gigantic review project is debatable. The present volume is not suitable for the non-specialist, and in some of the fields discussed even the pure nuclear scientist would find himself in this class.

The title is misleading. Mathematics occurs *passim*, as it must in any paper on physics, but there is little attempt to present any mathematics as a logical whole. More irritating, some of the mathematics is described in words rather than in symbols. This does not make it easier reading for either mathematicians or non-mathematicians.

L. R. B. ELTON

PHYSICS OF REACTORS

Peaceful Uses of Atomic Energy. Proceedings of the International Conference in Geneva. Vol. II, Physics, Research Reactors. Pp. 471. Vol. III,

Power Reactors. Pp. 389. Vol. IV, Cross-Sections Important to Reactor Design. Pp. viii + 357. Vol. V, Physics of Reactor Design. Pp. viii + 545. United Nations, New York; Her Majesty's Stationery Office, London. 1956. 57s., 54s., 54s., and 63s. net respectively.

The International Conference on the Peaceful Uses of Atomic Energy, held in Geneva during August 1955, was the occasion for the release of a great fund of technical information on all aspects of the subject. These four volumes contain the proceedings of the sessions which discussed, in considerable detail, present knowledge on the physics and design of all types of nuclear reactors. The papers presented, together with the admirably reported discussions, allow a comparison to be made of the present achievements and future programmes of the various countries engaged in this field.

Considering the volumes in order, the first half of volume II contains papers on a number of important topics in basic nuclear physics, in particular, fission physics and inelastic neutron scattering. The second half covers the construction of, and operating experience with, a number of research reactors. The reactors described include swimming-pool reactors, water boilers, and the United States reactor for testing materials, light and heavy-water-moderated reactors of the U.S.S.R., the Saclay reactor of France, J.E.E.P. of Norway, and B.E.P.O. of the United Kingdom. The importance of this type of reactor for providing information on the design of reactors for high powers is well demonstrated.

Volume III is clearly one of the most important volumes of the Proceedings, because it contains an account of the design of all the large-power reactors at present under detailed consideration. One of the most striking features is the wide diversity of possible designs, all aimed at the development of economic power plants. Not unnaturally, only a few of the reactors described are in operation. Accounts of operating experience are limited to the water-cooled graphite-moderated enriched uranium reactor of the Soviet Union, the American boiling-water reactor, and the EBR I sodium-potassium-cooled fast reactor. It is apparent that these three reactors are experimental projects rather than full-scale power plants.

The combined papers in volume IV give an excellent survey of the experimental methods for measuring nuclear

characteristics of fissile materials. Much attention is given to the various time-of-flight techniques, using either a mechanical chopper or a pulsed-neutron source, for making measurements with neutrons of a known energy. The wealth of numerical data quoted makes this volume one of the most comprehensive reference books on this subject so far published. In many cases, where similar measurements have been made by American, British, and Russian laboratories, there is remarkable agreement between the values quoted.

Volume V contains the papers which deal with the nuclear physics problems associated with reactor design. The reactor problems discussed cover thermal, intermediate, and fast neutron systems. Many of the papers deal with experimental observations on reactors and their theoretical interpretation. The lack of continuity between the different papers is perhaps more apparent in this volume than in the others. However, this is offset by the large quantity of experimental data on reactor physics which has been collected into one volume.

J. E. R. HOLMES

HYDROGEN PEROXIDE

Hydrogen Peroxide, by W. C. Schumb, C. N. Satterfield and R. L. Wentworth. Pp. xiii + 759. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1955. 132s. net.

The widening applications of hydrogen peroxide have greatly stimulated the study of its manufacture and properties. It is therefore timely that the first comprehensive volume on this subject in English should now appear. The authors are particularly well qualified for the task since they themselves have made valuable contributions to knowledge of the subject.

An interesting historical introduction is followed by two extensive chapters on methods of formation and manufacture. This information is given in adequate detail, but the reader will find the authors have drawn much on published information about German practice. An outline of the autoxidation process, now operated industrially, is given, but the book was published before information was released on another organic method of production based on the oxidation of isopropyl alcohol.

The physical and chemical properties are particularly well treated. The

data on physical and thermodynamic properties are well chosen, and the effect on radiation is dealt with in some detail. One chapter is almost entirely devoted to structure, while another discusses the mechanism of reaction and outlines the reactions with inorganic and organic compounds. Decomposition in the vapour and liquid phase is extensively dealt with, and there is an authoritative discussion of stability problems. The scope of the analytical section is rather limited, while the uses of the material are treated in descriptive outline, including reference to applications in the propulsion field. The final chapter gives a useful but summarized account of inorganic peroxy compounds.

The whole work is pleasingly presented, and the authors have compiled a book which should become a standard reference for some time to come.

W. S. WOOD

ORGANIC CHEMISTRY

Lehrbuch der organischen Chemie (third/fourth edition), by Hans Beyer. Pp. xvii + 690. S. Hirzel Verlag, Leipzig. 1955. DM. 22.50 net.

This is a completely revised edition of a general textbook of organic chemistry in which much attention is paid to the electronic theories of reaction mechanisms. Classification of reactions is introduced early (under alkyl halides); the reactions of olefins bring in the discussion of π -bonds; polymerization is shown as a rational process; recent contributions of German research and technology are described. Petroleum, plastics, stereochemistry, chemotherapy, coenzymes, the citric acid cycle, and alkaloids are all competently dealt with. Because the information on most topics has been skilfully selected, it is difficult at first to see how so much ground has been covered. There are omissions in some sections which many readers will regret; for example, carotenoids are dealt with in four pages by omitting discussion of degradations, syntheses, or even colour. There is a confusing lack of uniformity in the method of printing the formulae of ring compounds: to note only one example, the carbon atoms are omitted from naphthaquinone (p. 431), while anthraquinone (p. 436) has exaggerated C=O groups attached. But the general effect of the book is to give the reader a fascinating picture of the scope of organic chemistry, especially of its recent triumphs. The author's style is clear and

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the printing is good. For honours students this book should provide stimulating views of the subject. J. C. SMITH

ORGANIC CHEMISTRY

Perspectives in Organic Chemistry, edited by Sir Alexander Todd. Pp. x + 527. Interscience Publishers, New York and London. 1956. 55s. net.

This tribute to Sir Robert Robinson on the occasion of his 70th birthday, consisting of eighteen essays by leading authorities in Europe and America, among whom are some of Sir Robert's many distinguished former students, is far more than a conventional *Festschrift*. Possibly the contours of organic chemistry have become so enlarged during the twentieth century that never again will it be possible for any one man to acquire so penetrating an insight into, and wield so wide and decisive an influence on, the subject as a whole as Sir Robert has done.

It is not possible to give an account of all the topics included in the present 'Perspectives'; suffice it to say that they cover practically all modern organic chemistry and that they should primarily serve, as stated by E. L. Hirst, not so much for 'taking stock of achievement in a field which has become static, as for indicating some of the many growing points and the general nature of the problems which are to be faced'.

Alkaloids, biosynthetic theories, steroids, the concepts of aromaticity, resonance, and reaction mechanisms are all represented with a delightful lucidity which will ensure that this work will live as a reference book for many years to come. No organic chemist can fail to find this volume rewarding from cover to cover, and its usefulness is increased by the many references and structural formulae. It is perhaps invidious to select individual chapters for comment, but Woodward's 'Synthesis' is surely outstanding for its elegance and its emphasis on planned approaches having special reference to modern selective methods and reagents. Todd on nucleic acids, Butenandt on genetics, Ziegler on metallo-organic syntheses, and Pauling on resonance represent other fascinating articles in this valuable collection. I. M. HEILBRON

ORGANIC CHEMISTRY

A Textbook of Practical Organic Chemistry, including Qualitative Organic Analysis (third edition), by Arthur I. Vogel. Pp. xxvii + 1188. Longmans,

Green and Company Limited, London. 1956. 60s. net.

In this edition the whole text has been exhaustively revised, and a twelfth chapter on semi-micro technique added. A 16-page appendix is devoted to infra-red and ultra-violet spectroscopy. Now that each page prominently bears its chapter and section number, reference from one section to another is greatly facilitated. The book does succeed in giving a full, clear account of the techniques of organic chemistry in one volume, but omission of all references to the sources of the great mass of information provided reduces its usefulness.

Qualitative analysis is authoritatively dealt with, but there is one change from the wording of the second edition which may lead to errors. On page 1041, in testing for nitrogen in presence of sulphur, it is recommended that the precipitate of ferrous sulphide be filtered off before acidification of the filtrate. Experience shows that in this procedure the ferrocyanide is usually removed with the sulphide.

The book, which is remarkably free from errors, is well written and produced. It should be available in every chemical laboratory. J. C. SMITH

POLYESTERS

Polyesters and their Applications, by J. Bjorksten, H. Tovey, B. Harker, and J. Henning. Pp. viii + 618. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1956. 80s. net.

In a book of over 600 pages it must be almost unique to find the bibliography beginning on page 253. The authors and their collaborators have classified over 1000 relevant patent references and more than twice that number of references to technical articles and books. The amassing of this wealth of information is the *raison d'être* of the whole book and to the potential user an invaluable time-saver. A simple introduction to the general concept of polymer chemistry is followed by a general review of manufacturing and processing techniques. Pride of place goes to the unsaturated polyesters, whose tonnage far exceeds that of the saturated compounds, which find their main outlet as melt-spun fibres.

The market for unsaturated polyesters, mainly as reinforced thermosetting resins, is very diverse and favours small-scale operations. This is brought out by the chapters on fillers,

shaping, and finishing, and a survey of available commercial resins, followed by an interesting chapter on 'Tailor Making Polyesters'.

The balance between low cost of raw materials and tooling and comparatively high processing cost determines the applications to which polyesters are put: some discussion of the economics of the subject would, therefore, not have been out of place. C. I. RUTHERFORD

GEOMAGNETISM

Lectures on Rock Magnetism, by P. M. S. Blackett. Pp. 131. The Weizmann Science Press of Israel, Jerusalem. 1956. \$5 net.

The remarkable fact that many rocks are apparently able to retain a record of the magnetic field prevailing at the time of their formation has aroused considerable interest. Professor Blackett has made valuable contributions to the subject by his improved design of the astatic magnetometer and through his leadership of an active group of workers in the field. The present volume is a stimulating discussion of the results so far obtained. Because the study of rock magnetism makes contact at various points with a number of widely differing geological and physical subjects, such as palaeoclimatology, the physics of the earth's crust, and the theory of ferromagnetism, it is not to be expected that Professor Blackett's exposition will satisfy the various specialists in these fields.

Little is said, for example, about the evidence for polar wandering, although this is stronger than the magnetic evidence at present available for continental drift. Further, the statistical treatment of results, which is absolutely essential if measurements of rocks from different places are to be compared, is dismissed with a comment that 'they would give an undue impression of accuracy'. To exhibit the results obtained by his group on the Triassic sandstone of England, the author uses histograms and radial polygons of declination and inclination where the use of the well-known stereographic projection is much to be preferred.

The discussion of the results on the Pilansberg dykes of South Africa appears to the reviewer to be misleading. The results of Gough are compared with those of the author's group on the Triassic rocks of Great Britain and France, and are held to show that Africa and Europe have drifted as a

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unit. However, the age of the Pilansberg dykes is definitely earlier than Permian and may be Pre-Cambrian, while the author gives their age variously as 300 or 400 million years, nearly twice that of the British and French rocks with which he is comparing them.

S. K. RUNCORN

BIOCHEMISTRY

Currents in Biochemical Research, 1956, edited by David E. Green. Pp. xvi + 697. Interscience Publishers Inc., New York; Interscience Publishers Limited, London. 1956. \$10 net.

This volume is the third of a series of essays with which the present editor has been associated. The series began in 1936 with a volume edited jointly by Dr Green and Dr Joseph Needham; a second volume was edited by Dr Green in 1946. The outstanding success of these volumes prompted Dr Green and the publishers to collect a new series after an interval of ten years. Their aim has been 'to communicate to non-specialists an overall impression of the present status of the significant problems in each field, to point up the broad strategy of current research, and finally, to speculate on the likely paths of future research'. Dr Green has succeeded in securing the collaboration of twenty-seven leading biochemists, including M. Calvin, B. Chance, C. F. Cori, L. F. Leloir, F. Lipmann, D. Nachmansohn, E. Racker, F. Sanger, D. Shemin, S. Spiegelman, H. Theorell, while the editor himself contributes a preface outlining the major achievements and trends of contemporary biochemistry. The level of the essays certainly matches those of the previous volumes. The articles make most stimulating and informative reading, alike to the specialist working in the field and to the scientist working in remoter subjects, including the non-biochemist. The contributors have taken an unusual opportunity of discussing their chief interests from a general point of view and of expressing speculative thought.

H. A. KREBS

CHROMOSOME BOTANY

Chromosome Botany, by C. D. Darlington. Pp. xii + 186. George Allen and Unwin Limited, London. 1956. 16s. net.

Professor Darlington is intensely aware that many aspects of botany as taught in both universities and schools have degenerated into arid formalism. That this is so is only too evident from the questions set in examinations, a

number of which could well have been set a hundred years ago. The situation in botany, in fact, is similar to that conceived by Newman when referring to another discipline. 'We have a vast inheritance, but no inventory of our treasures. All is given to us in profusion; it remains for us to catalogue, sort, distribute, select, harmonize, and complete. We have more than we know how to use; stores of learning, but little that is precise and serviceable'.

This book is of great importance because it does attempt to co-ordinate the known facts of chromosome behaviour, and because it brings to university students a whole new integrated approach to fundamental aspects of both pure and applied botany. This urgently needed synthesis may ultimately permeate both school and university teaching.

It is by no means a perfect book. The author is often engaged in goading, and pursuing with guided missiles charged with heavy sarcasm, helpless and already defeated conventional taxonomists, who are after all worthy individuals.

Many geneticists would not accept the author's ideas about the 'polygene' as set out on page 4. The statement is here made that 'polygenes... are sometimes recognizable; in the resting nucleus they wear a thick coat of sticky, nucleic acid and at metaphase they may suffer from the reverse conditions of nakedness or nucleic acid starvation. They are known as heterochromatin.' The book is somewhat marred by such personal opinions and surmises, but perhaps unavoidably, since they are the vivid expression of genius and should so be interpreted by students.

S. G. HARLAND

BRITISH FLORA

The History of the British Flora, by H. Godwin. Pp. viii + 384. Cambridge University Press, London. 1956. 90s. net.

The purpose of this book is to describe the methods available for the historical study of the British flora and the results so far achieved, both with special reference to the Quaternary era. After a brief summary of the materials available—seeds, fruits, leaves, wood (sometimes as charcoal), and pollen grains—the author proceeds to a discussion of Quaternary chronology. The use and correlation of biological, archaeological, and physical (radio-carbon) methods of dating are given detailed and critical consideration, and the importance of bog stratigraphy as

an index to prevailing conditions comes in for special mention.

These background chapters are followed by a detailed plant list giving the historical records of more than 700 species, including cereals and other crop plants. The amount of information it is possible to provide (as judged by the length of the individual entries) appears to be correlated with the abundance of pollen produced by the species—a sufficient indication of the pre-eminence of palynology in this field. Finally, a description is given of the changing pattern of the vegetational cover of the islands during the vicissitudes of the Quaternary age, with its successive glaciations and interglacial periods leading down to medieval times.

Throughout the book the emphasis is on the direct evidence obtainable from suitable sites. The aim is stock-taking, and the attitude one of caution against premature definitive pronouncements.

The text is printed in double columns on a large page and is abundantly and handsomely illustrated in line and half-tone.

W. O. JAMES

PARASITES

Parasites and Parasitism, by Thomas W. M. Cameron. Pp. xix + 322. John Wiley and Sons Inc., New York; Methuen and Company Limited, London. 1956. 35s. net.

This book, as the author explains, is not a textbook of medical or veterinary parasitology. Too often, he thinks, the real nature of parasitism is clouded by the concept of disease, and in this work he tries to get away from this. Writing for readers who have a 'working knowledge' of biology but no special knowledge of parasitology, he devotes the first section to the bacteria, fungi, spirochaetes, rickettsias, viruses, and Protozoa; the second to the coelenterates, tapeworms, flukes, and roundworms; the third to the ringed worms (Annelida), the arthropods, the molluscs, and the few vertebrates that have adopted parasitism. The rest of the book deals with the host and its reactions, parasitism, infectious disease, the distribution of parasites, their control, and their host-specificity and evolution. The book ends with a bibliography, a glossary, an outline of the zoological classification of parasites, and an index.

The well-written text will stimulate thought. Some readers may disagree with some of the author's views, but these are based on his extensive original

work on parasites and on many years of teaching. The book is attractively produced, and the original and instructive line illustrations add much to its value.

G. LAPAGE

ANATOMY OF BEES

Anatomy of the Honey Bee, by R. E. Snodgrass. Pp. xiv + 334. Cornell University Press, New York; Constable and Company Limited, London. 1956. \$6 net.

The first work on the anatomy of the honey-bee by the author was published in 1910 as one of the early Technical Bulletins of the United States Department of Agriculture, and many of the admirable line drawings prepared at that time reappear in this book. In 1925 the work was expanded to form the 'Anatomy and Physiology of the Honey Bee'; for many years this both provided an excellent survey on the honey-bee itself and served as a most useful primer on the physiology of insects in general. In its present form the book has been virtually rewritten. It now deals almost exclusively with matters of structure, and does so in the clear masterly style that we have come to expect from the doyen of insect anatomists. As always, Snodgrass is constantly interested in the functioning of the structures described; but of 'physiology' little remains, and naturally enough that does not always reflect current ideas. But on its real topic, the anatomy of the bee, the book appears to be admirably up to date, even including some references of 1956.

V. B. WIGGLESWORTH

MAMMOLOGY

Traité de zoologie. Vol. XVII. Mammifères. Les ordres: anatomie, éthologie, systématique, edited by P.-P. Grassé. Pt. I, pp. 1170; Pt. II, pp. 1171-2300. Masson et Cie, Paris. 1955. Pt. I: paper covers, Fcs 11 000 net; bound, Fcs 11 800 net. Pt. II: paper covers, Fcs 11 000 net; bound, Fcs 11 800 net.

The difficulty of writing a satisfactory zoological treatise is particularly apparent when dealing with Mammals and Man, where the data come from such varied sources. That Professor Grassé and his colleagues have mastered the problem successfully is shown above all by the fact that their great work is readable. The writing is fresh and terse; the typography and illustrations are excellent. One reads on through order after order, happy to recognize old facts in fresh settings and to learn many new ones. The book

triumphantly demonstrates that the facts of animal life can be well presented around a framework of anatomy. The arrangement of the book follows a well worn morphological plan laid down by Cuvier, Owen, Gegenbaur, and Goodrich, to mention only a few. With an outline of the organization of each animal type as a basis it is then possible to proceed to relate a mass of facts about the physiology, reproduction, bionomics, and behaviour of the animals.

J. Z. YOUNG

OTOLOGY

British Medical Bulletin, Vol. XII, No. II (Neuro-Otology). Pp. 91-160. The British Council, London. 1956. 15s. net.

In the words of Sir Bryan Matthews in his introduction, 'the present number of the *Bulletin* gives clear evidence of the active state of otological research and its present fruitfulness'. Authoritative articles by workers in Britain on such varied topics as the technique of cutting histological sections of the internal ear, the formation and chemistry of endolymph and perilymph, the physiology of hearing and of the vestibular apparatus, the diagnosis and treatment of different types of deafness, the pathology and symptomatology of disorders of the labyrinth and of the central connections of the eighth nerve, and the hereditary lesions of the labyrinth in 'dancing mice' appear under the general editorship of C. S. Hallpike, who himself is author or part-author of four of the contributions.

The emphasis in most cases is naturally on the clinical applications of recent additions to knowledge, but physiologists, pathologists, anatomists, and zoologists will welcome this valuable survey no less than otologists and neurologists. Particularly striking are the advances which have been made by the use of modern techniques in electrophysiology, of pure-tone electronic audiometers, of refined caloric tests, and of very delicate microchemical analysis.

R. S. CREED

CEREBRAL CORTEX

The Organization of the Cerebral Cortex, by D. A. Sholl. Pp. xvi + 125. Methuen and Company Limited, London; John Wiley and Sons Inc., New York. 1956. 18s. net.

It is pleasing to find such a clear and concise account of the cerebral cortex. Inevitably, much has been omitted or treated in a summary fashion, yet the book is not superficial. Dr Sholl has

restricted the account throughout to those features of the cerebral cortex which appear to him to be significant for the understanding of its mode of operation. It is valuable to have his well informed criticism of the old topographical work. In fact the whole book is remarkable for the very high level of critical comment. The constructive side is less notable. The new quantitative histology seems still to be too rudimentary for the development of precise hypotheses relating to cortical activity. Yet there is great promise in this attack, and Chapter 4 is a particularly valuable exposition of Dr Sholl's fine work on the 'Quantification of Neuronal Connectivity'. The chapters on physiological, clinical, and psychological investigations provide good summaries, but will appear inadequate to specialists. For example, most neurophysiologists would regard synapses as structures highly specialized for the operation of chemical transmitters, and not characterized merely by a close apposition of two nervous structures. Again, there is now no justification for assuming that electrical fields are effective in neuronal interaction, and the 'domain' hypothesis of Cragg and Temperley thus has no sound experimental foundation. The related theory of Beurle avoids this criticism and provides an excellent illustration of Sholl's thesis that the functioning of the cortex should be treated in terms of a model that is based on the concept of probability and is discussed in statistical language.

J. G. ECCLES

MEDICAL RESEARCH

Ergebnisse der medizinischen Grundlagenforschung, Vol. I, edited by K. Fr. Bauer. Pp. vi + 855. Georg Thieme Verlag, Stuttgart. 1956. DM. 129 net.

This is one of a new series of short monographs dealing with topics which form the scientific background of medicine. The editor states as the reason for this new venture that other reviews address themselves in the first instance to specialists and are often unsuitable for the clinician; it is the aim of the present series to present articles comprehensible to medical scientists who have no intimate knowledge of the basic sciences. The volume contains nineteen papers. They are selected from a wide range of subjects, including biochemistry, biophysics, allergy, embryology, histology, nutrition, endocrinology, and bacteriology. Morphology is represented by a review by

Ashton and Zuckerman entitled 'Measurement and Number in Morphology'. The majority of the authors are drawn from Germany and the papers are all published in German, but Sweden, Switzerland, Japan, France, Great Britain, and the United States are also represented. Many of the articles fulfil the editor's intentions and are likely to be of real value to medical scientists.

H. A. KREBS

ATMOSPHERIC POLLUTION

Atmospheric Pollution—Its Origins and Prevention (*second edition*), by A. R. Meetham. Pp. viii + 302. Pergamon Press Limited, London. 1956. 63s. net.

Since the first edition of this book appeared, increased attention has been focused on the evil effects of air contamination. The second edition is an attempt to bring the work up to date in the light of the considerable new information elicited at many conferences in Britain and America and by the reports of the Air Pollution Committee appointed by the British Government.

The additional matter is dealt with in a new chapter of 32 pages. For its size, the scope of the book is ambitious. It covers the whole range of relevant subjects—the origin and availability of fuels; the properties of wood, peat, and all members of the coal series in their raw and prepared states; hazards of mining; petroleum and natural gas; carbonization and hydrogenation; generation of steam and electricity; industrial furnaces and domestic fireplaces—before proceeding to the main theme of atmospheric pollution in all its details. The author has succeeded in presenting this all-embracing compilation in a readable form by clearly outlining principles rather than by dilating on descriptive details.

The author frankly admits having called on his judgment and conjecture more frequently in the new chapter than in other parts of the book. He certainly gives full rein to his ingenuity when he explains the physics of the formation of the catastrophic London fog of December 1952. He considers a rectangular area of 450 square miles covered by a stagnant mass of air 500 ft deep. The estimates and calculations of liquid and vaporous water contained in, lost from, and added to this mass, and the setting up of balances of smoke, sulphur, halogens, and oxides of carbon, as well as the toxicity caused, are well worth a close study, however

much the numerical values may differ from the unfortunately unascertainable truth.

R. LESSING

PESTICIDES

Chemistry and Uses of Pesticides (*second edition*), by E. R. de Ong. Pp. vii + 334. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1956. 70s. net.

The chemical industry now provides an almost bewildering range of toxic substances or 'pesticides' for those concerned with the prevention or eradication of insect, fungal, plant, and rodent pests. There has thus developed a need for authoritative books which explain the nature and uses of pesticides and their hazards: Dr de Ong has supplied one such book. In view of their dependence on climatic conditions, availability of suitably trained personnel, etc., control methods may differ greatly from one part of the world to another. It is not surprising, therefore, that Dr de Ong has largely confined his treatment of pesticide formulation and application to conditions obtaining in the United States. His book deals in turn with inorganic pesticides, petroleum products and pesticide solvents, fumigants, pesticides derived from plants, and the more recent synthetic organic compounds. A final chapter briefly treats the use of 'cold, heat, dehydration and radiation'. The direct use of beta and gamma irradiation by radioisotopes or high-voltage machines is, however, not discussed. An extensive appendix tabulates and classifies some 400 pesticides available in the United States. Final sections deal with pesticide residues permissible in food products in the United States, and with first aid for operators.

For a second edition there are a large number of minor errors: for example, methyl bromide and bromoethane are taken to be synonymous. The book will be useful to practical students of agriculture and to those concerned with the control of pests in a wide sense. F. P. W. WINTERINGHAM

ESSENTIAL OILS

Die ätherischen Öle (Gildemeister-Hoffmann), Vol. IV, edited by W. Treibs and K. Bournot. Pp. xxxii + 720. Akademie-Verlag, Berlin. 1956. DM. 55 net.

This is part of the fourth edition of the well-known handbook originated by E. Gildemeister and F. Hoffmann.

At present about 2400 plant species are known to contain essential oils (as compared with about 1370 in 1931 when the original was published). The increase in number, and developments in methods for extracting and characterizing essential oils, have caused the new edition to expand to seven large volumes. Volume IV describes the relatively few essential oils from cryptogams, and commences the discussion of the much more numerous essential oils associated with seed-bearing plants. Turpentine and other oils of the conifers are fully covered, together with the volatile oils of nearly forty dicotyledonous families. Among the latter are the technically important scented grass oils (palmarosa, lemongrass, citronella, etc.) and those of orris, ginger, sandalwood, star anise, nutmeg, etc.

The treatment is exhaustive, and the layout, typesetting, and indexes are excellent. The complete series will assuredly maintain the tradition of the original classical monographs.

T. P. HILDITCH

MOLYBDENUM

Metallurgy of the Rarer Metals, No. 5: Molybdenum, by L. Northcott. Pp. xii + 222. Butterworths Scientific Publications, London; Academic Press Inc., New York. 1956. 40s. net.

Molybdenum has hitherto been used mainly as a constituent of special ferrous alloys, with a minor application of the pure metal in the form of filaments for valves, etc. However, with the advent of new techniques for processing high melting-point metals the possibility of widening the scope of the application of molybdenum has become greater. This book is therefore most welcome in providing potential users with a background of information on the mechanical, physical, and chemical properties. The subject matter follows the general trend used in other volumes of this series. Chapters are included on extraction and refining of molybdenum, general physical and mechanical properties of the pure metal and its alloys, fabrication, arc-melting, and various methods of joining. The alloying characteristics of molybdenum are clearly summarized and include constitutional data on 32 binary, and various ternary, alloys. The oxidation of the pure metal and selected alloys is discussed together with present methods of affording protection. Valuable bibliographies are provided at the end of each chapter. B. W. MOTT

Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

The Condensed Chemical Dictionary (fifth edition), by Arthur and Elizabeth Rose. Pp. xix + 1200. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1956. 100s. net.

While this is a valuable reference work for all chemists, it is especially so for those concerned with industry and commerce. It gives a wealth of information about the properties, derivation, uses and trade names of a wide range of commercially available chemicals; it should be noted that some information such as that on specification, containers, and shipping regulations relates specifically to American practice. This new edition is very substantially larger than the fourth edition of 1950, which has been completely revised and brought up to date.

The Historical Background of Chemistry, by H. M. Leicester. Pp. viii + 260. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1956. 48s. net.

This book deals comparatively little with the biographies of chemists, and places the main emphasis on the development and interrelation of chemical concepts. Although much of the book is devoted to the period before chemistry came to be regarded as a science in its own right, the last chapters deal with modern times, and include discussion of radioactivity and atomic structure and of biochemistry.

pH Measurements. Their Theory and Practice, by Victor Gold. Pp. 125. Methuen and Company Limited, London; John Wiley and Sons Inc., New York. 1956. 9s. 6d. net.

This addition to Methuen's well known series of monographs on chemical subjects describes the basic theory of pH and the principal methods of measuring it. It includes a chapter on the pH concept in relation to non-aqueous solvents. The book is written for the general scientific reader and assumes no detailed knowledge of physico-chemical theory.

Hydrogen Ions. Their Determination and Importance in Pure and Industrial

Chemistry. Vol. 2 (fourth edition), by Hubert T. S. Britton. Pp. xix + 489. Chapman and Hall Limited, London. 1956. 75s. net.

This volume provides the advanced chemist with a detailed discussion of the role of hydrogen ions in chemistry and in a number of important industrial processes, such as tanning, sugar refining, water purification, and ore flotation. An important addition since the third edition of 1942 is a description of electrometric methods for the titration of acids and bases in non-aqueous media.

Paper Electrophoresis, edited by G. E. W. Wolstenholme and Elaine Millar. Pp. xii + 224. J. and A. Churchill Limited, London. 1956. 35s. net.

This is an account of a three-day symposium on paper electrophoresis arranged by the Ciba Foundation in London in July 1955. The symposium included both general papers—for example, on high-voltage techniques—and papers on special applications. Particular emphasis was laid throughout on identification of the factors responsible for differences between results obtained in different laboratories, so that reliable comparisons can be made.

Times and Places, by the late Harold Peake and H. J. Fleure. Pp. xv + 336. Clarendon Press, Oxford; Cumberlege, London. 1956. 42s. net.

This is the tenth and last volume of the 'Corridors of Time' series, which is designed to give the general reader an account of human evolution from the beginning until the civilizations of classical times in the Mediterranean. About one-fifth of the book deals with comparatively recent work on man in the Old Stone Age. The second part deals with the origin and spread of methods of food production.

Physiologie de l'insecte (second edition), by Remy Chauvin. Pp. 917. Institut National de la Recherche Agronomique, Paris. 1956. Fcs 3500 net.

In preparing the second edition the author has completely revised the text of the first and extended it by some 300

pages: the bibliography now comprises almost 2800 references. In the revision particular attention has been given to the chapters on the integument, moulting, diapause, and sexual hormones.

Automation in Theory and Practice, by E. M. Hugh-Jones. Pp. ix + 140. Basil Blackwell, Oxford. 1956. 12s. 6d. net.

This comprises a series of lectures on automation given in Oxford in 1955. The subject is considered from many points of view—including that of the scientist, engineer, trade unionist, and economist. The book concludes with a three-page bibliography.

Grandes découvertes du xx^e siècle, edited by Louis Leprince-Ringuet. Pp. 503. Librairie Larousse, Paris. 1956. Fcs 2705 net.

This book, in the characteristic Larousse style, attempts a comprehensive survey of modern science written at the level of the general reader. It is well illustrated and covers a remarkably wide field, but the emphasis is on the physical rather than the biological sciences.

Lecture Notes on the Use of the Microscope (second edition), by R. Barer. Pp. v + 76. Blackwell Scientific Publications, Oxford. 1956. 7s. 6d. net.

This is a basic elementary text for all students who have to use a microscope. The emphasis is on practical instruction, but there is a short section on theory.

Spot Tests in Organic Analysis (fifth edition), by Fritz Feigl. Translated by Ralph Oesper. Pp. xx + 616. Elsevier Publishing Company, Amsterdam; Cleaver-Hume Press Limited, London. 1956. 55s. net.

This fifth edition of a very well known work takes note of the considerable progress made by Professor Feigl and other workers in the field since the last edition appeared only three years ago. More than eighty new tests, some not previously published, are described, and there is a new section on the identification of substances of medicinal interest.

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ENDEAVOUR

A quarterly review designed to record the
progress of the sciences in the service
of mankind

VOLUME XVI

July 1957

NUMBER 63

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Communications to the Editor should be addressed to North Block, Thames House, Millbank, London, S.W.1

The start of the International Geophysical Year

The great enterprise known as the International Geophysical Year—in which 56 nations are co-operating—has been planned as a concerted attack on many problems relating to the various earth sciences, for whose solution concurrent observations in different regions of the world are required. The planning stage has now been completed. The operational stage formally commenced on 1st July, 1957, although test observations were made at most stations during the preceding weeks to ensure that all equipment was in correct adjustment and that observers were thoroughly familiar with the techniques involved.

The planning of the programme has been the responsibility of the Special Committee for the International Geophysical Year, appointed by the International Council of Scientific Unions. This Committee held a preliminary meeting in Brussels in 1953, and full meetings in Rome in 1954, in Brussels in 1955, and in Barcelona in 1956. At the last two of these meetings it met in conjunction with an Advisory Committee, composed of one representative of each nation participating in the programme. A National Committee has been set up in each participating country to formulate the national share in the general programme. Recent discussions have resulted in modifications in some details of national plans, whereby a better distribution of observing stations was secured. Regional conferences have been held to discuss matters of special importance and interest to particular regions. They have included three conferences on the Antarctic, and one each on the Arctic, the western hemisphere, Eastern Europe, and the Western Pacific.

A feature of the International Geophysical Year will be the special attention given to the Antarctic, where simultaneous observations of geophysical phenomena at a number of stations have never previously been made: in neither of the two International Polar Years (1882–3 and 1932–3) were there any stations in the Antarctic. Within the Antarctic Circle there will be 57 observing stations, manned by twelve countries. Many of the stations on the Antarctic Continent were set up during the summer of 1955–56, and observations at some of them are already in progress. For communication between stations in the Antarctic, and between them and the outside world, a com-

plete network of radio communications has been arranged. Call-signs have been allotted for each of the fixed stations and for many others operating from sledges, tracked vehicles, and aircraft. Provision has been made for direct intercommunication between all these stations, and for direct links from them to distant capital cities. Reports on meteorology, on other scientific observations, and on administrative and personal matters can thus be sent speedily and accurately. Frequencies for the various stations have been selected so as to avoid mutual interference between stations as far as possible.

The International Geophysical Year has been timed to cover a period when solar activity is at or near its maximum. Because of the various terrestrial effects resulting from disturbances on the Sun, it is important that particularly intensive observation should be made while such disturbances are in progress. But accurate prediction of the occurrence of a disturbance is not possible, though solar observations may indicate the probability that one is impending. To warn observers to be on the alert for the outburst of a disturbance, a world warning agency has been set up at Fort Belvoir, near Washington, a radio field station of the U.S. National Bureau of Standards. On the basis of information received from solar observing stations this agency will decide when to announce an alert. Should further information indicate that a disturbance is to be expected, the warning agency will declare a Special World Interval, which will start eight hours after the warning message has been given. More intensive observations in the various disciplines will then commence, and will continue until the Interval is cancelled, if the disturbance fails to materialize, or until the disturbance has subsided or the disturbed area has passed round the limb of the Sun. The warning messages will be issued at 1600 UT daily, whenever there is a state of alert or a Special World Interval, and will state whether either is to be continued or terminated.

Regional warning centres have been established in Western Europe, Eurasia, the Western Pacific, and the western hemisphere; there are also several associate centres, for example in Antarctica and Australia. The world warning agency will send a direct telegram to all regional warning centres and will also arrange for suitable signals to be

transmitted twice daily on the WWV standard-frequency broadcasts of the Bureau of Standards. Each regional warning centre will assemble summaries of current observations of geomagnetic and auroral data, of solar flares, radio fade-outs, and other phenomena, on the basis of information received, and will be responsible for distributing such information by telegrams to all stations within its region. Codes for all messages from the world and regional warning centres have been formulated.

A special feature of the observational programme will be the employment of rockets and satellite vehicles to extend observations to heights far beyond the maximum height of about 30 km that will be reached by balloons. The United States, the Soviet Union, Great Britain, and France have rocket programmes. The rockets will penetrate through the ozone layer of the atmosphere and enable the solar spectrum to be photographed into the far ultraviolet and X-ray regions. Some will carry magnetometers for the detection and measurement of the circulating current sheets whose existence has been assumed in order to account for some of the observed variations in the Earth's magnetic field. Direct measurements will be made of the ion and electron densities in and between the several ionized layers of the ionosphere. The temperature, pressure, density, and composition of the atmosphere up to great heights will be determined. It is hoped that among the rocket flights a few will occur at times when a major disturbance is taking place on the Sun.

The duration of the flight of a rocket is limited to a few minutes. The United States and the Soviet Union plan to supplement the information obtained from rocket flights by launching satellite vehicles which will circle the earth at a height of a few hundred miles and will send information back to the earth by radio. The United States has announced that it hopes to launch up to twelve artificial satellites during the course of the Year; the first of these launchings will be made in the early part of next year. The satellite, which will have a diameter between 20 and 30 in, will be launched from a three-stage rocket. It will be projected, when at a height of 200–300 miles, in a horizontal direction with a speed of 18 000 miles per hour. The orbit that it is hoped to obtain is slightly elliptical, reaching a distance of about 800 miles from the Earth at apogee. The plane of the orbit will be inclined at an angle of 40° to the equator; as the Earth rotates, the satellite, circling the globe in about 90 minutes, will pass over

different regions of the Earth's surface during each revolution. Each satellite will carry complex instruments specially designed on a small scale; these are now in course of development. It will send radio signals to the Earth, where ground radar installations will be used to track its course. An elaborate organization has been arranged for securing visual and photographic observations, with provision for very accurate timing.

The resistance of the atmosphere will cause the satellite gradually to lose energy and to spiral inwards towards the Earth. As it reaches denser regions of the atmosphere it will become heated and will finally disintegrate and be vaporized, very much like a shooting star. An electronic computer will be used to compute its orbit, and it is expected that information about the density of the atmosphere at different heights will be derived. Ultraviolet and X-ray radiation from the Sun will be measured; the Earth's magnetic field above the ionosphere will be investigated; cosmic radiation will be studied by counter techniques, and, in particular, information will be obtained about the lower-energy end of the cosmic ray spectrum. Some information may be gained about micro-meteorites and about the densities of dust and of hydrogen atoms and ions in the upper atmosphere. The Soviet Union has plans to launch one or two satellites, but no information has yet been given of the nature of the orbits to be attained.

The observational data that will be accumulated during the eighteen-month programme of the International Geophysical Year will provide the basis for the investigation of a great variety of problems in geophysics. Many years must elapse before the data can be fully analysed. The important problem of how best to make the data available to geophysicists has been considered by the Special Committee. It has been decided to establish three World Data Centres—one of which will be in the United States, one in the Soviet Union, and the third in Western Europe—where copies of observations, magnetographs, ionograms, and so on will be stored. Instruction manuals have been prepared for the guidance of observers in the various disciplines in the maintenance and adjustment of equipment, in the interpretation and scaling of records, and in the uniform presentation of results.

The start of this tremendous enterprise is the culmination of years of detailed planning throughout the world. We send our good wishes for its success to all those who have made it possible and to those taking part in the observational programme.

Control of metabolic processes

H. A. KREBS

Biochemical research over the past thirty years has established that the principal metabolic processes proceed through a number of intermediate stages. What may be called the qualitative analysis of metabolic processes is now beginning to be followed by a quantitative one. This analysis seeks to elucidate the factors which determine the rates of individual metabolic processes and ensure that the complex series of biochemical changes that continuously take place in a living organism assume a pattern appropriate to its needs and environment.

Investigations into metabolic processes during the last three decades have been concerned mainly with the elucidation of the intermediary stages and with the properties of the enzymes controlling each stage. Thanks to the new tools which have become available—such as the techniques of enzymology, the use of isotopes, and chromatographic and optical methods of analysis—success has not been lacking, and the main stages of intermediary metabolism are now known. This is true for both the degradation of foodstuffs and the processes that transfer the energy derived from this degradation; it is true also for many synthetic reactions, especially those leading to the formation of constituents of low molecular weight, like fatty or amino acids.

While many details of the metabolic pathways still remain to be established, interest has recently been shifting towards other aspects of intermediary metabolism, in particular the mechanisms which govern metabolic rates [1-4]. It is well known that these are not constant, but vary with the physiological state of the cell. They may increase many times over, for example, when a tissue such as muscle or a gland changes from rest to activity. The type of metabolic process within cells may change when the environment changes. Thus energy may be obtained by oxidations if air is available, or by fermentations of sugar if it is not. It follows that cells possess mechanisms which adjust metabolic activities to changing needs.

Control of biological processes is commonly

taken to be the function of hormones and of the nervous system, and there is no doubt that both play a part in some of the mechanisms which control reaction rates in higher organisms. But control mechanisms also occur in lower forms of life, such as the unicellular ones, where hormones and nerve cells are absent. These 'primitive' control mechanisms [5] are also present in higher animals; they are, in fact, the basic systems on which the action of hormones or the nervous system is superimposed.

Knowledge of intermediary metabolism and of enzyme systems has sufficiently advanced in recent years to prepare the ground for a study of these 'primitive' mechanisms which operate in controlling the rate of metabolic processes, and to give tentative answers to the question of how cells adapt the rates of some reactions to changing needs. This is particularly true of the processes supplying energy, and the following discussion will be mainly concerned with this aspect of metabolism.

THE ROLE OF ENZYME AND SUBSTRATE

The basic unit which determines the rates is the enzyme-substrate system. The quantities of enzyme and of substrate together limit the maximum rates which can be reached under any given conditions. Such maximum rates are exceptional under physiological conditions, the limiting factor being usually, but not always, the amount of substrate: the fact that intermediate products do not usually accumulate shows that the substrates of the intermediary enzymes are removed as rapidly as they are formed. The average half-life of the acids of the tricarboxylic acid cycle in a rapidly respiring tissue is a few seconds [6]. The amounts of enzyme in the tissue are sufficient to deal with the intermediates as soon as they arise; in other words, the amount of available substrate is the factor limiting the rate at which the intermediary step proceeds.

This conclusion is borne out by the fact that

The following abbreviations have been used in the formulae in this article:

ATP	..	..	adenosine triphosphate
ADP	..	..	adenosine diphosphate
ITP	..	..	inosine triphosphate
IDP	..	..	inosine diphosphate
DPN	..	..	diphosphopyridine nucleotide
DPNH ₂ ..	..	..	reduced diphosphopyridine nucleotide
CoA or HS-CoA	..	..	coenzyme A
P	..	..	orthophosphate

addition of the intermediates often increases the rate of intermediary processes. The intermediates of the tricarboxylic acid cycle, for example, all stimulate the rate of respiration of suitable tissue preparations [7]. This indicates that the enzymes attacking the added substrates are not used to full capacity when endogenous substrates, such as glucose, are oxidized. That analogous considerations apply to the anaerobic lactic acid fermentation is shown by the fact that animal tissues can form lactic acid more rapidly from hexose diphosphate than from glucose [8].

PACEMAKERS OF METABOLISM

Although, then, the rate of many intermediary steps of metabolism depends mainly on the concentration of the substrates, this is not true for all steps. There are some reactions, though comparatively few, where the rates depend on factors other than the amounts of enzyme or substrate. These are the 'pacemakers' of metabolism: they are the reactions which are evidently of special interest in relation to the control of metabolism. Their study presents two main problems: the first is the identification of the pacemakers, the second, the analysis of the mechanism by which their rates are controlled.

There is a general principle that may guide the search for pacemakers. As pacemakers are reactions of variable rates, the level of substrate concentration of the pacemaker must vary with the rate. It must increase when the reaction rate decreases, though whether the rise is appreciable would depend on the equilibrium position of the preceding step. The study of the concentration level of intermediary metabolites, especially the change of steady-rate concentrations caused by a change of environmental conditions, may therefore provide information on the nature of pacemakers and control mechanisms. F. Lynen [2, 9], for example, found that the change from aerobic to anaerobic conditions in fermenting yeast cells is accompanied by a rise in orthophosphate within the cells, which indicates that a reaction involving phosphate is one of the pacemakers of fermentation. Information on the steady-state levels of intermediary metabolites is still very limited, however, owing to lack of adequate methods of analysis. Several laboratories are now engaged in elaborating analytical techniques [4, 11, 12].

PACEMAKERS OF ANAEROBIC GLYCOLYSIS

Of the twelve major steps of anaerobic glycolysis (figure 1), two have been assumed by various

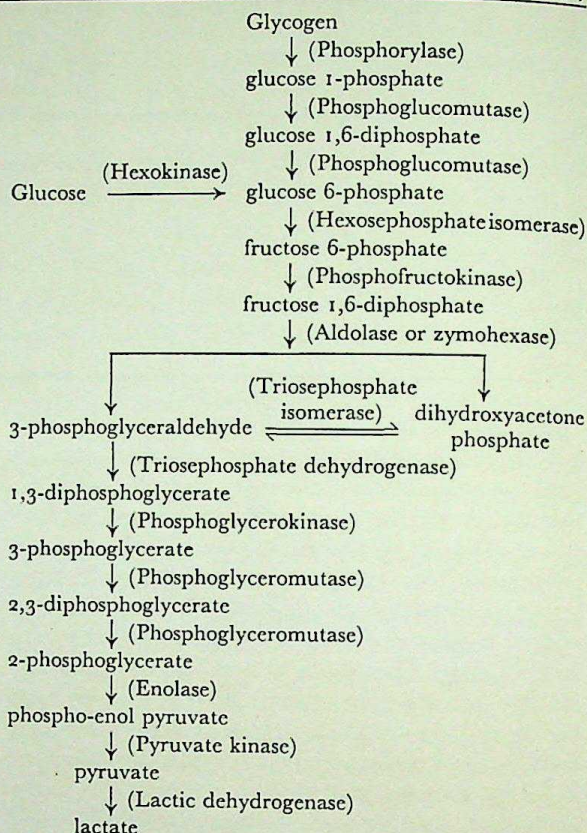


FIGURE 1 — Lactic acid fermentation (anaerobic glycolysis). Intermediary changes of the carbon skeleton of carbohydrates. The enzymes concerned in the various stages are shown in brackets.

authors to act as pacemakers of anaerobic glycolysis. The first is the hexokinase reaction [8], by which glucose is converted to glucose 6-phosphate, ATP acting as the phosphorylating agent. This reaction probably initiates all major metabolic reactions of glucose: the anaerobic fermentation, the complete oxidation, and the transformations into glycogen, fat, amino acids, or other cell constituents (figure 2). While the hexokinase reaction (or a reaction very closely connected with it, possibly the penetration of glucose to the site of hexokinase) evidently determines the rate of glucose consumption, it cannot control the energy production from glucose because of the variety of pathways open to glucose 6-phosphate.

The triosephosphate dehydrogenase reaction has been taken to be the second pacemaker which decides the rate of energy production from glucose 6-phosphate. This is a complex reaction in which diphosphopyridine nucleotide, adenosine phosphate, and orthophosphate take part (figure 3). It is obvious from the formulation that the reaction

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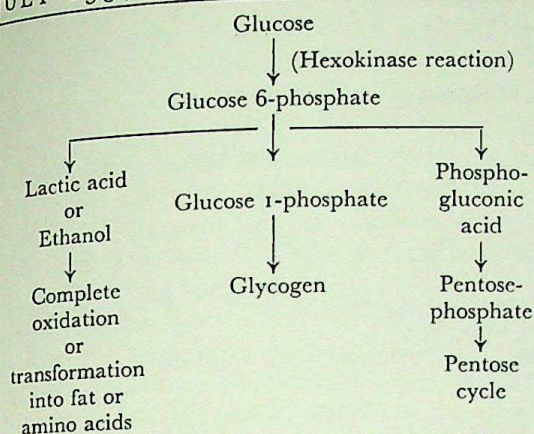


FIGURE 2 — Diagrammatic presentation of the alternative pathways of metabolism open to glucose and glucose 6-phosphate.

cannot take place unless adenosine diphosphate and phosphate are available—the very two substances which become available when energy is spent. It must be understood, however, that the rate control is due not so much to the presence or absence of these reactants as to the level of their concentrations: the rate decreases even before adenosine diphosphate or phosphate disappears completely. It also follows that the rate of the triosephosphate dehydrogenase reaction may be

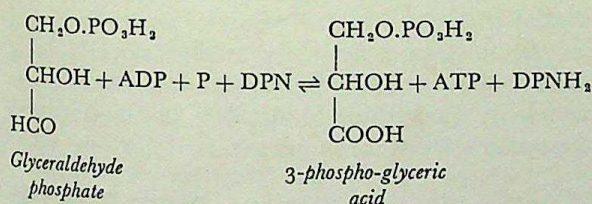


FIGURE 3 — Overall change in the triosephosphate dehydrogenase systems. This is the result of two major steps, catalysed by triosephosphate dehydrogenase and by phosphoglycerokinase respectively (Bücher [10]).

influenced by any process which either removes or supplies adenosine diphosphate or phosphate. The main reaction which removes these two reagents is respiration, coupled with oxidative phosphorylation. Hence respiration must inhibit fermentation; this is the interpretation of the Pasteur effect (the inhibition of fermentation by oxygen) proposed by M. J. Johnson [1] and by F. Lynen [2]. On the other hand, any energy-requiring process will, within limits, stimulate fermentation because it generates adenosine diphosphate or phosphate.

While it is very probable that this mechanism operates, some aspects of glucose utilization remain to be clarified, as F. Lynen and R. Koenigsberger [9] have pointed out. Stoppage of the triosephosphate dehydrogenase reaction can ex-

plain stoppage of lactic acid formation, but it does not account for the decreased utilization of sugar. Non-removal of triosephosphate would lead to an accumulation of fructose diphosphate, because of the ready reversibility of the aldolase reaction (see figure 1). But the stage between fructose 1:6-diphosphate and fructose 6-phosphate is not readily reversible. Hence the accumulation of triosephosphate or fructose 1:6-diphosphate cannot, by mass action, prevent the hexokinase reaction or the conversion of glucose 6-phosphate into fructose 6-phosphate and fructose 1:6-diphosphate. On the contrary, the relatively high concentration of adenosine triphosphate required for the inhibition of the triosephosphate dehydrogenase reaction is expected to facilitate the formation both of glucose 6-phosphate and of fructose 1:6-diphosphate from glucose or from glycogen. Thus additional factors must be responsible for the decrease of sugar consumption when conditions change from anaerobiosis to aerobiosis. Lynen and Koenigsberger [9] have raised the question whether the rate of the hexokinase reaction might be controlled by the hexosephosphates formed. An important observation in this context is the non-competitive inhibition of hexokinase by glucose 6-phosphate, discovered by H. Weil-Malherbe and A. D. Bone [13] and further investigated by R. K. Crane and A. Sols [14]. Glucose 6-phosphate in as low a concentration as 0.5×10^{-3} M causes 40 per cent inhibition. It is certainly feasible that this inhibition, or analogous effects at other stages of glycolysis, play a part in the control mechanism, but before this can be accepted, further investigations are needed, especially of the steady-state concentrations of the phosphorylated intermediates, of the kinetics of the enzyme systems concerned, and of specific inhibitions by intermediary metabolites.

It has also been considered whether the reduction of sugar consumption in the presence of oxygen might be caused by a direct action of oxygen on an enzyme, for instance by the oxidation of an —SH group which might inactivate an enzyme reversibly [15–17, 9], but the evidence argues against this kind of mechanism. Under a variety of conditions fermentation can reach the anaerobic level in the presence of oxygen, as, for example, on addition of dinitrophenol or isonitrite.

PACEMAKERS OF RESPIRATION

When energy is released by the oxidation of carbohydrate, fat, and amino acids, there are over a hundred identifiable intermediate steps, only a

few of which are pacemakers. Pacemakers are expected at two types of stages of respiration: first, at those where the total oxygen consumption (i.e. energy supply) is determined, and secondly at those where, after a partial degradation, more than one pathway is open.

It follows from the fact that intermediates do not accumulate that those steps which initiate the oxidation of a substrate must be among the pacemakers of respiration. These reactions also decide which substrate, among a mixture, is attacked preferentially—whether carbohydrate, fatty acids, or amino acids serve as a source of energy. Branching stages, where more than one pathway can be entered by an intermediate metabolite, occur at many points. Examples are given in figure 4, which shows diagrammatically the major stages of the metabolism of carbohydrate and fatty acids where branching of pathways may take place. It is decided at these branching points whether glucose is broken down to supply energy or stored in the form of glycogen; whether glucose, via acetyl coenzyme A, is converted into fat or whether fat is broken down to give energy; whether ketone bodies are formed from fatty acids or acetyl coenzyme A or disposed of via the tricarboxylic acid cycle; whether intermediates of the tricarboxylic acid cycle are oxidized, or used to supply carbon skeletons for the synthesis of amino acids, porphyrins, or steroids.

ENZYMIC PATTERN OF CONTROL MECHANISM

The analysis of the control mechanisms which operate in these pacemaker reactions must begin with a translation of the situation into the terminology of enzyme chemistry. Two types of situation may be distinguished. Alternative metabolic routes may arise either from a choice of alternative reactions (say breakdown of either carbohydrate, or fat, or protein when energy is needed), or from a choice of alternative directions of pathways (say synthesis or breakdown of fatty acids). In the first case the reactions which take place are essentially different; in the second the same reactions move in opposite directions.

Closer examination of the first case shows that the alternative reactions which occur when cells have the choice of obtaining energy from a variety of substrates are not entirely independent processes. The oxidation of a substrate by molecular oxygen generally involves three types of catalysts, arranged in series. They are respectively the pyridine nucleotides, flavoproteins, and iron por-

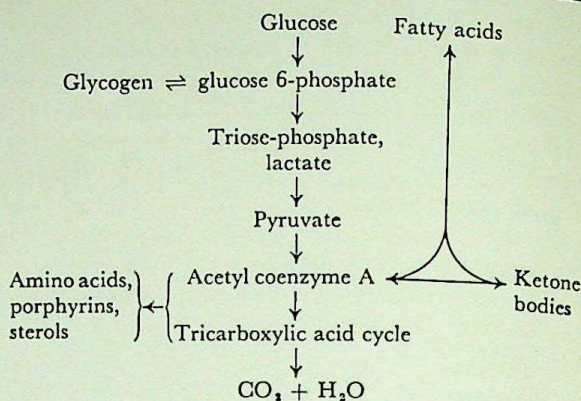


FIGURE 4—Examples of branching points in the intermediary metabolism of carbohydrates and fatty acids.

phyrins. Only the first step of this complex sequence varies from substrate to substrate. All other intermediate steps are shared by the alternative reactions, as shown diagrammatically in figure 5. Five substrates, representing the great majority of metabolites supplying energy, are chosen to illustrate the principle. The oxidation begins in every case with a transfer of hydrogen atoms to a common reagent, diphosphopyridine nucleotide.

Partial exceptions are fatty acids and succinate, but in these cases most intermediate steps are also shared with the other substrates. Fatty acids and succinate donate hydrogen atoms directly to a flavoprotein, a deviation from the general rule which is necessitated by the thermodynamic characteristics of these substrates.

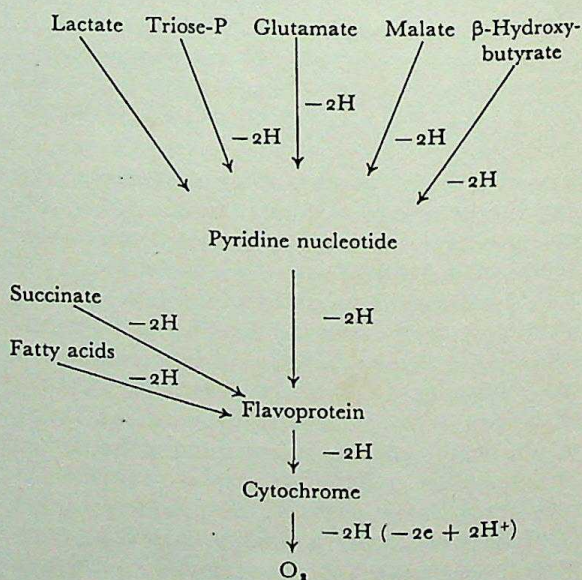


FIGURE 5—Joint pathways of hydrogen transport from different substrates to molecular oxygen.

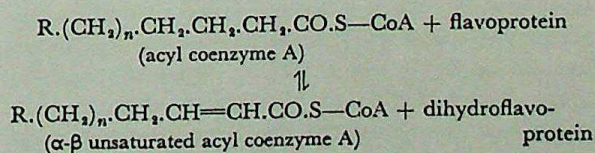
Of a similar type, also involving competition, seems to be the control mechanism at one of the branching points of metabolism where the fate of acetic acid, reacting in the form of acetyl coenzyme A, is determined. Among the major pathways open to acetyl coenzyme A in liver tissue is the conversion into acetoacetate (ketogenesis) or the complete oxidation to carbon dioxide and water through the tricarboxylic acid cycle (antiketogenesis) (figure 4). Acetoacetate arises by condensation of two molecules of acetate, while the oxidation via the tricarboxylic acid cycle requires condensation of acetate with oxaloacetate. This suggests that the availability of oxaloacetate is the key factor in controlling ketogenesis and antiketogenesis [18]. However, experimental tests in the intact organisms failed in many cases to bear out this view: succinate, which readily supplies oxaloacetate in the body, does not relieve acidosis in human diabetics [19] or in the rat [20]. Some decrease in urinary ketone body excretion in rats made ketotic by excess butyrate occurs, however, when various precursors of oxaloacetate are administered by stomach tube [21]. On the other hand, oxaloacetate is certainly antiketogenic in isolated mitochondria. Fatty acids yield ketone bodies in liver mitochondria in the absence of oxaloacetate, but they are oxidized through the tricarboxylic acid cycle when oxaloacetate is added [22]. The availability of oxaloacetate can thus, at least under certain conditions, decide whether ketone bodies accumulate or fatty acids are completely oxidized.

Experiments with substances which interfere with the tricarboxylic acid cycle, and thereby reduce the supply of oxaloacetate, lead to the same conclusion. Malonate, which prevents the oxidation of succinate, and ammonium ions, which divert α -ketoglutarate to glutamate, are both ketogenic [23]. These are observations which point to the key role of oxaloacetate, but it cannot be claimed that the mechanism controlling ketogenesis is fully understood, seemingly because of insufficient information on the factors which control the steady-state level of oxaloacetate. At least

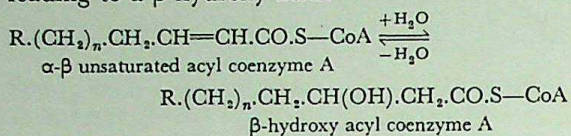
malate + DPN	$\rightleftharpoons$ oxaloacetate + DPNH ₂ (malic dehydrogenase)
phosphopyruvate + CO ₂	$\rightleftharpoons$ oxaloacetate + ATP (or ITP)
+ ADP (or IDP)	(Utter-Kurahashi reaction)
aspartate + α -keto-glutarate	$\rightleftharpoons$ oxaloacetate + glutamate
	(transaminase)
oxaloacetate + H ₂ O	$\rightleftharpoons$ pyruvate + HCO ₃ ⁻ (oxalo-acetic decarboxylase)
oxaloacetate + acetyl coenzyme A	$\rightleftharpoons$ citrate + coenzyme A (condensing enzyme)

The availability of oxaloacetate can account for the formation or non-formation of acetoacetyl coenzyme A. Free acetoacetate appears in appreciable quantities only in liver. This is accounted for by the fact that liver contains an enzyme which hydrolyses acetoacetyl coenzyme A (deacylase) and, unlike most other tissues, cannot convert free acetoacetate back to the coenzyme A derivative [24]. This illustrates the obvious point that presence or absence of specific enzymes contributes to the control of pathways.

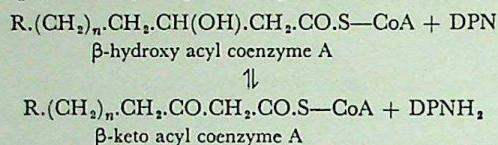
The cases so far considered have been concerned with the mechanisms by which alternative pathways of metabolism are selected. There is another pattern of enzymic mechanism, however, when the alternatives are different directions of the same reaction: an example is the synthesis or breakdown of fatty acids. Long-chain fatty acids are broken down and built up by the removal or addition of C_2 -units reacting in the form of acetyl coenzyme A. In breakdown and synthesis there are four reversible reactions for each molecule of acetyl coenzyme A [25, 26]. In breaking down, the first step is the dehydrogenation of the fatty acid chain in the α - β position, leading to the formation of an α - β double bond, the immediate hydrogen acceptor being a flavoprotein:



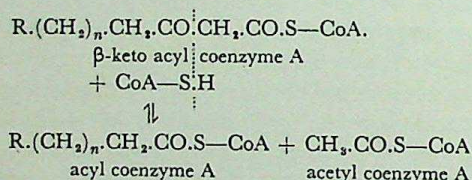
The second step is hydration of the double bond, leading to a β -hydroxy acid:



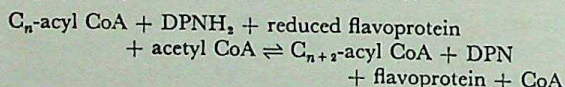
This is followed by the dehydrogenation of the β -hydroxy acid to a β -ketonic acid, with DPN as the primary hydrogen acceptor:



The fourth step is the 'thiolysis' of the β -ketonic acid by a molecule of coenzyme A, yielding acetyl coenzyme A and an acyl coenzyme A with two carbon atoms less than the original:



In reverse, these four reactions lead to the elongation of fatty acids, and the question arises of what determines whether synthesis or degradation occurs in the reversible system. The sum of the four reactions causing shortening or lengthening of fatty acid chains is as follows:



Being reversible, the reaction proceeds from left to right when the values for the three ratios

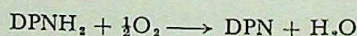
$$\frac{\text{acetyl CoA}}{\text{CoA}}, \frac{\text{reduced flavoprotein}}{\text{oxidized flavoprotein}}, \frac{DPNH_2}{DPN}$$

are relatively high, and from right to left when the ratios are relatively low. In the intact body, fat is generally synthesized when there is a surplus of carbohydrate, i.e. when pyruvate is available to form more acetyl coenzyme A than is required for energy production by the tricarboxylic acid cycle. Concomitant with the formation of acetyl coenzyme A from pyruvate occurs the reduction of diphosphopyridine nucleotide and, indirectly, of flavoprotein. Thus excess of pyruvate raises the above three ratios, whereas lack of carbohydrate lowers them. It can therefore be understood, in general terms, why fatty acids are broken down in the absence, and synthesized in the presence, of

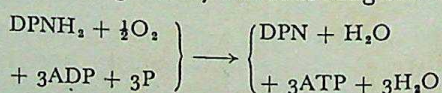
carbohydrate. It can also be understood why fat synthesis is impaired in diabetes and why insulin is necessary for fat synthesis [5]. The utilization of carbohydrates in higher organisms requires the presence of insulin: hence absence of insulin reduces the oxidative formation of pyruvate, which in turn reduces the supply of acetyl coenzyme A and lowers the ratio $DPNH_2/DPN$ [28].

There are other syntheses in which the mechanisms controlling the balance between synthesis and breakdown cannot yet be satisfactorily visualized, mainly because the enzymic reactions have not been sufficiently clarified. The principles operating in the fatty acid system are probably factors in many cases.

The pacemakers of respiration so far considered illustrate the manner in which the choice between alternative metabolic processes can be controlled. There remains to be discussed the mechanism which regulates the rate of oxygen consumption or aerobic energy supply. This is determined by the reactivity of the system of catalysts which governs the oxidation of organic substrates by molecular oxygen; in other words, by the rate at which reduced diphosphopyridine nucleotide, reduced flavoprotein, and reduced cytochrome transmit hydrogen atoms or electrons to O_2 . The hydrogen-transport from reduced diphosphopyridine nucleotide to O_2 , along the path outlined in figure 5, is known to be coupled with the synthesis of adenosine triphosphate from adenosine diphosphate and orthophosphate. Owing to this coupling, the reaction



and its component steps, proceed at full rate only if adenosine diphosphate and orthophosphate are present (although short cuts not involving phosphates may occur under special circumstances [26]). In fact, the oxidation of reduced diphosphopyridine nucleotide as formulated above is a 'part reaction', and a more correct representation of the position is given by the following scheme:



This coupling of oxidation and phosphorylation (oxidative phosphorylation) seems to be obligatory under physiological conditions, and the role of phosphate in this system is therefore comparable to that in the triosephosphate dehydrogenase reaction mentioned earlier. Both reactions depend on the supply of adenosine diphosphate and phosphate, and are thus controlled by the rate at

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which adenosine triphosphate is split to adenosine diphosphate and phosphate, i.e. by the amount of energy spent. As the rate of the interaction between substrates and diphosphopyridine nucleotide depends on the rate at which diphosphopyridine nucleotide is regenerated by the oxidation of reduced diphosphopyridine nucleotide, oxidative phosphorylation also controls the rate of degradation of the substrate.

These concepts are tentative. They are supported by substantial evidence, but cannot be regarded as established in detail. What is well established is the rate-limiting function of phosphate and/or phosphate acceptors under certain well-defined conditions. Earlier observations by A. Lennerstrand [29] and V. A. Belitzer [30] on rate control by phosphate and/or phosphate acceptors have been elaborated in particular by H. A. Lardy and H. Wellman [31], who showed that the rate of oxidation of a variety of substrates in liver mitochondria is accelerated by the addition of inorganic phosphate and of adenosine diphosphate or other phosphate acceptors [3, 4, 32-34]. Under some experimental conditions the rate-limiting factor is inorganic phosphate, under others it is the phosphate acceptor [35]. It is probable that *in vivo* both can play a role.

PACEMAKERS AS VULNERABLE STAGES OF METABOLISM

When specific chemicals, such as hormones, or drugs, or poisons, modify metabolic rates, it is likely that the point of attack is one of the pacemakers [36]. The primary effect of such agents is in most cases either inhibition or activation of an enzyme. Since the activity of non-pacemakers is not a factor limiting the rate, even a major inactivation or an activation of a non-pacemaker would not change overall metabolic rates, although it may change the level of the steady-state concentrations of intermediates.

Experimental observations agree with the view that the stages of cell metabolism liable to be influenced by inhibitors or hormones are usually the pacemaker reactions. Specific inhibitors of glycolysis interfere either with the hexokinase reaction (e.g. L-glyceraldehyde) or with the triosephosphate dehydrogenase system (e.g. iodoacetate). Specific inhibitors of respiratory processes interfere either with the electron-transport system (e.g. cyanide, azide, or sulphide) or with the step initiating the attack on the organic substrate, i.e. the dehydrogenase reaction (e.g. malonate). Other inhibitors upset the balance of reactants at

branching points, for example the ketogenic agents which reduce the supply of oxaloacetate in the liver. As for hormones, insulin is taken to control the rate of the hexokinase reaction, possibly indirectly by controlling the entry of sugar into the cells. The effect of thyroxine or triiodothyronine on the basal metabolic rate seems to be due to interference with the electron-transport system. The glycogenolytic action of adrenaline is due to an acceleration of phosphorylase, the enzyme which initiates the degradation of glycogen [37]. In all the examples the point of attack is a pacemaker reaction.

GENERAL COMMENTS ON THE DESIGN OF THE 'PRIMITIVE' CONTROL MECHANISMS

If the hormonal control of biological activities operates generally through an effect of the hormone on the activity of an enzyme, the non-hormonal control mechanisms discussed in this paper are in principle of a different kind. They usually belong to the type of systems which engineers call 'feedback' systems. Control by feedback is an arrangement in which the controlled process, as it progresses, creates conditions unfavourable for further progress, and thereby causes the rate to slow down. This slowing down recreates more favourable conditions and thereby speeds up the progress. Thermo-regulators are among the simplest examples of feedback systems.

Mechanisms controlling metabolic rates include in many cases arrangements of this type. The key substances through which the controls governing the energy supply are operated are inorganic phosphate and adenosine diphosphate. Their presence stimulates the rate of both the aerobic and the anaerobic degradation of foodstuffs. When energy is spent, the concentrations of these two substances are bound to rise. The increased rate of respiration or fermentation in turn causes their removal and thereby eventually decreases the rates of the energy-supplying reactions.

Competitive mechanisms, in which diphosphopyridine nucleotide is one of the key substances, may also be looked upon as feedback systems. When two substrates compete for a common intermediary catalyst, each by its presence creates unfavourable conditions for the reaction of the other substrate. As one of the substrates disappears, the second is automatically 'fed' to the catalyst, so that approximate constancy of catalytic activity is secured.

The relative contributions made in higher animals by hormonal control and feedback

control may be illustrated by the example of the energy-supplying reactions. While hormones, in particular that of the thyroid, play an important role in the control of the basal metabolic rate, the energy needs due to functional activity, such as contraction by muscles or secretion by glands, are primarily controlled by feedback mechanisms. It is true that hormones may control secretion and thereby influence the rate of energy supply, but these effects of hormones on the rates of energy supply are probably indirect and achieved through the mediation of feedback mechanisms.

Feedback mechanisms occur at many levels of biological organization. The long-known effect of the alveolar carbon dioxide pressure on breathing [38] is an example. Others concern the heart beat

[39] and especially the activities of the nervous system, including those of the higher centres. The purposeful behaviour of biological systems in particular can in many cases be accounted for in an entirely mechanistic manner by hypotheses based on the feedback principle [40].

So far, no more than a beginning has been made in the elucidation of the basic chemical mechanisms which control the nature and the rate of metabolic processes, but an insight has already been gained into some of the principles involved. The adaptation of the reaction rates to changing needs can be understood, at least in part, on the basis of the properties of the enzyme systems, inhibitions and feedback arrangements being the distinctive features of the control mechanisms.

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Macquer, the first lexicographer of chemistry

DOUGLAS McKIE

Macquer's *Elémens de chymie théorique* (1749) and his *Elémens de chymie-pratique* (1751) established him as the leading French writer on chemistry and the successor of Nicolas Lemery. But his greatest work—his dictionary, virtually an encyclopaedia—came fifteen years later. This passed through many editions, both in French and in translation into foreign languages, and had a powerful effect on the development of chemistry at a time of revolutionary change.

Pierre-Joseph Macquer, one of the distinguished chemists produced by eighteenth-century France, was born in Paris on 9th October 1718, the elder of the two sons of Joseph Macquer and his wife, Marie-Anne Caillet. Philippe, his younger brother, was born on 15th February 1720. His father was said to be descended from a noble Scots family who had taken refuge in France after having lost all their possessions through their devotion to the Catholic faith and the Stewart cause. Macquer does not seem, however, to be either a Scots name or a corruption of one; nor would it appear to have been derived from Ker, since the noble families of that name were not supporters of the Stewarts. The writer has suggested elsewhere [1] that Macquer is a corruption of Maguire, the family name of the ill-fated house of Enniskillen. Many of the Jacobite entries in the parish registers of Saint-Germain-en-Laye, where James II and his court found refuge, agree with this suggestion; thus it seems probable on the evidence that Macquer was of Irish rather than Scottish descent.

It is said that the Macquers insisted that their sons should take up professions. Such insistence probably came from the father, with memories of a half-century of poverty among his fellow exiles. Philippe,

the younger brother, elected for the law, but, on account of his ill health, eventually turned to history and literature, and in these subjects became well known for the exactness of his scholarship and the clarity of his literary style. Pierre-Joseph, on the other hand, chose medicine; not, it would seem, through any deep love of that art, but because it disagreed less than any other calling with his growing taste for the physical sciences. In 1742, at the age of 24, he graduated doctor of

medicine in Paris. He had, however, been specially interested in chemistry, and in 1745 he was elected to the *Académie des Sciences* as *adjoint-chimiste*, in succession to Paul-Jacques Malouin, who had been promoted *associé*. Macquer himself became *associé* in 1766 and *pensionnaire* six years later, in 1772. He served as deputy director of the *Académie* in 1773 and as director in 1774.

Macquer studied chemistry at the *Jardin du Roi* under Guillaume-François Rouelle (1703–70), an account of whose work and teaching has already been given in this journal [2]. Rouelle was regarded by his French contemporaries as the founder of chemistry in France, where he had introduced and taught the phlogiston theory, which, in spite of what has been said against it by those who have not fully grasped



FIGURE 1 – Pierre-Joseph Macquer (1718–84), Professor of Chemistry in the Jardin du Roi in Paris, and first lexicographer of chemistry. From an engraving by Benoist after a portrait by Garrand. (Courtesy of the Bibliothèque Nationale, Paris.)

its role in the historical development of chemistry, had the great merit of taking chemistry out of the hands of the alchemist and the apothecary. Rouelle's chemistry was, however, not entirely free from some of the familiar characteristics of the apothecary's art: it was at the hands of Rouelle's pupil, Macquer, that French chemistry finally lost these features and became a science that stood on its own. To this important and significant change Macquer contributed both by his teaching and by his numerous books. Before turning to consider these, however, it would be appropriate to devote a little time to his early researches.

His first published memoir in the annual volume of *Mémoires de l'Académie* dealt with the solubility of oils in spirit of wine (1745). Then followed two other memoirs on salts of arsenic (1746 and 1748) and another on chalk and plaster (1747). In a paper on Prussian blue (1752) he showed that this substance was a combination of iron with something that the alkalis extracted from the animal matters used in its preparation. For over thirty years similar publications continued—on dyestuffs, fusible earths, platinum, the solubility of salts in spirit of wine, mineral waters, and similar topics. In the meantime, however, Macquer had begun to teach the subject that had captured his whole interest and attention.

In 1757, in collaboration with Antoine Baumé (1728–1804), Macquer began to give courses on chemistry in their laboratory in the rue Saint-Denis, Paris. Baumé was a master-apothecary and was demonstrator in chemistry at the college of pharmacy: he was the author of many papers and books. Notable among the latter is his *Chymie expérimentale et raisonnée* (Paris, 3 vols, 1773), in which he embodied the results of sixteen of these annual courses given in association with Macquer; in each of these more than two thousand experiments were demonstrated. Macquer himself, in 1770, obtained from Buffon the reversion of Bourdelin's chair of chemistry in the *Jardin du Roi*, took the oath in 1771, and succeeded to the chair on Bourdelin's death in 1777.

Macquer's *Elémens de chymie théorique* first appeared in 1749 in Paris. It was a small octavo single volume of about 350 pages, with three plates



FIGURE 2—An engraving—probably by Benoît Audran (ob. 1772), after a painting by Teniers of an alchemist in his laboratory—from the first page of the text of the second edition (quarto) of Macquer's *Dictionnaire de Chimie* (Paris, 1778).

of chemical apparatus and a reproduction of Geoffroy's table of chemical affinities. When the most famous of all textbooks of chemistry, the *Cours de chymie* of Nicolas Lemery (1645–1715), which had first appeared in 1675 in Paris, was still current in one or other of its many revised editions, not only in France but also throughout Europe in translations into English, German, Latin, Italian, and Spanish, and when the great quarto edition (Paris, 1756) of nearly 1000 pages was still to come, Macquer's modest little book must have seemed a slight affair. But it dealt with the principles of chemistry and with the different classes of chemical substances and their chemical properties; significantly, it said nothing about their pharmaceutical properties, in spite of what might have been expected from Macquer's interests as a physician. Rouelle's teaching, it would appear, had here achieved one of its most important consequences, and the success of this new writer on chemistry, whose approach was so different in that he presented his subject as an independent branch of natural knowledge and as a science in itself, was immediate.

Two years later, a further work by Macquer appeared, the *Elémens de chymie-pratique* (Paris, 1751), in two octavo volumes with a total of over 1000 pages. A new edition of the earlier book on theoretical chemistry followed in 1753. Then in 1756 there was a new edition of that book in one volume and one of the book on practical chemistry in two volumes, forming altogether three volumes of some 1500 pages. Macquer had now taken his place as the leading French writer on chemistry and his reputation grew quickly. An English version of his book, under the title 'Elements of the

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Theory and Practice of Chemistry', translated by Andrew Reid, appeared in two octavo volumes in London in 1758; there was a second edition in 1764, dedicated to the Earl of Bute. A third edition in three volumes was published in Edinburgh in 1768. This was dedicated 'To the STUDENTS at the UNIVERSITY of EDINBURGH and all other LOVERS of CHYMISTRY'; it remains one of the most attractive of all the editions of this work. Another English edition, probably a fourth, has been reported as published in London in 1775. A fifth edition, in one volume, came out in Edinburgh in 1777: a copy of this edition is now before the present writer, with two loose slips carrying notes apparently in the hand of Joseph Black, to whom it may have belonged. Indeed, the appearance of the editions of 1768 and 1777 in Edinburgh may be connected with Black's very strong recommendation of Macquer's book to the students attending his chemistry class in the University. Black placed Macquer's 'Elements' first among 'the most necessary books', according to a student's notes taken down from Black's lectures, and he added that the work 'contains a clear and concise account of most of the facts relating to chemistry'. The author [3] has shown elsewhere that Black was recommending this book to his students as early as the university session of 1767-68. The *Elémens* was translated also into German, Dutch, and Russian.

It is, however, for his *Dictionnaire de chymie* (Paris, 1766, 2 vols, octavo), the first of its kind, that Macquer will always be remembered. Although he was already established as a writer, the first edition of this book appeared anonymously. It was a considerable work of some 1300 pages, but it was less a dictionary than a compact treatise on the science of chemistry, with the details presented in a series of about 500 articles arranged alphabetically. A reimpression of this first French edition followed in 1769, a Swiss edition in three volumes having been published meanwhile in 1767. An English translation in two volumes by James Keir (1735-1820) appeared in London in 1771; a second edition of this followed in 1777, in three volumes with an appendix consisting of a treatise on the various kinds of permanently elastic fluids or gases. German, Danish, and Italian versions appeared later. A further Swiss edition appeared in Neuchâtel in 1789 in five volumes, the fifth volume being a supplement dealing with more recent advances.

Further issues of a second French edition were published in Paris in 1778, an edition described as

second having, however, come out in three volumes in 1777. The edition of 1778 appeared in two formats, one of four octavo volumes and the other of two handsome quartos. The latter came from the *Imprimerie de Monsieur*, that is, from the press of which the elder of the King's brothers, the Comte de Provence, was patron. This quarto edition is one of the most beautifully produced of all works on chemistry and is still a collector's piece. An engraving of Teniers' picture of an alchemist in his laboratory, from the opening page of the text, is reproduced in figure 2. Its two volumes contain nearly 1600 pages, including an index in double columns running to 200 pages; this was necessary because of the book's encyclopaedic character.

Comparison of the two French editions of 1766 and 1778 shows that in the latter many of the earlier articles were greatly extended and also that many new ones were included, as was necessary in view of the great developments in chemistry that had taken place between these dates. To appreciate these revolutionary changes in chemical knowledge we need merely to recall that it was only in 1766, the year of the first edition, that Cavendish had isolated and recognized 'inflammable air' (hydrogen) and that the discovery of the gases had then rapidly opened up a whole new field of pneumatic chemistry, especially at the hands of Priestley. In the second edition, therefore, there were about fifty new articles, besides, as we have noted, much additional matter inserted in the text of those published in the first edition.

The modern reader interested in the history of chemistry instinctively turns to certain articles in a work of this kind. One of these will probably be that dealing with the chemical elements. Macquer, in 1766, is singularly modern in what he says: 'Those bodies are called by chemists *elements*, which are so simple, that they cannot by any known method be decomposed, or even altered; and which also enter as principles, or constituent parts, into the combination of other bodies, which are therefore called compound bodies.' However, in the next sentence the reader will find that Macquer has the ancient four-element theory in mind: 'The bodies in which this simplicity has been observed are fire, air, water, and the purest earth; for by the most complete and accurate analyses which have been made, nothing has been ever ultimately produced but some one, or more, of these four substances, according to the nature of the decomposed bodies. These substances, although reputed simple, may possibly not be so, and may even result from the union of several

other more simple substances: but as experience teaches us nothing on this subject, we may without inconvenience, and we ought to consider, in chemistry, fire, air, water, and earth, as simple bodies; because they really act as such in all chemical operations.' This was repeated in the second edition; in fact Macquer, in the absence of more exact knowledge, continued to accept the four-element theory, although making use of Boyle's definition of a chemical element.

The short article on alchemy is interesting, and we may quote it in full: 'This term has been employed by the pretended adepts, and by searchers after the philosopher's stone, to distinguish that kind of chemistry, the knowledge of which they flattered themselves was reserved for them alone. The adepts consider chemistry as a vulgar science, which scarcely contains the first elements of the mysterious science of alchemy. But hitherto they have produced nothing which, in the judgment of sensible men, can give the least grounds for such a pretention. True chemists consider alchemy as an imaginary science, and those who are devoted to it as persons who, from want of better instruction, quit a reality for the sake of a shadow.' The reader may thus be led to 'Adept', and he will find that this 'is the name assumed by those alchemists who claim to have discovered the secret of the philosopher's stone. See *Philosopher's Stone*.' On turning to the latter reference the reader will find that 'This name is given by alchemists to the preparation by which metals may be transmuted, gold and silver made, and all the wonders produced of (what they call) the *great work*.' Macquer's views about alchemists are clear from these quotations.

If we turn to the articles relevant to the contemporary struggle between the phlogiston theory and the new chemistry that was then being developed by Lavoisier, we find that Macquer had propounded a compromise between the old and the new. He was unwilling to abandon what the accepted theory of chemistry taught—namely, that in combustion and calcination phlogiston was set free from burning bodies and calcined metals—and yet was forced to consider the new experimental evidence adduced by Lavoisier that the gain in weight of metals on calcination was due to their combination with a part of the air. Macquer

therefore continued to assert that phlogiston, which he regarded as the matter of light, was set free in combustion and calcination, and that, while this admittedly led to a decrease in weight, the loss was more than made up by concurrent combination with air. This was a considerable modification of the phlogiston theory as originally propounded and as accepted in Macquer's time; it took Lavoisier's most skilful criticism and experimentation to refute such a compromise embracing both theories.

As Macquer's teaching and his writing had both been marked by clear and logical presentation, and as he had always had the reputation of opposing speculation that went beyond facts, it was most unfortunate that he should have been compiling his great dictionary during the most active years in which the new chemistry was arising from the old. Those who study his work closely are led to conclude that, but for his death in 1784 before the revolution in chemistry was complete, he might very readily have accepted the newer ideas. His dictionary of chemistry was the first of its kind, and it became a model of all those that have followed since. Nicholson's 'Dictionary of Chemistry' (London, 2 vols, 1795), the first dictionary of chemistry compiled in Britain, was constructed from Macquer's, and others that have since been produced here and elsewhere have followed the same model.

Macquer was much interested in the applications of chemistry. His well-known competence in such matters led to his appointment as director of the royal porcelain factory at Sèvres in 1766 in succession to Hellot, whom he succeeded also as director of the dyeing industries. He worked with Lavoisier and others on the official investigation into methods of improving and increasing the national production of saltpetre for the manufacture of gunpowder. He had also worked with Lavoisier when the latter was first studying the combustion of the diamond, and had earlier observed the slight flame produced when diamond was burnt. He had noticed too that the burning of a flame of 'inflammable air' against a cold surface produced drops of a liquid that appeared to be water.

Macquer died suddenly on 15th February 1784, in Paris.

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Mammalian spermatozoa

M. W. H. BISHOP and C. R. AUSTIN

Many branches of scientific enquiry have contributed to our knowledge of the spermatozoon and its functions. Its story is that of a highly specialized cell that can neither grow nor divide; that consists essentially of a condensed nucleus with means for locomotion and for penetrating the egg; that plays no role in the physiology of the animal that produces it; that is solely concerned with the production of new individuals of the kind from which it arose.

About 280 years ago, Johan Hamm of Arnhem saw spermatozoa in human semen and communicated his discovery to the eminent seventeenth-century microscopist Anton van Leeuwenhoek. Within a few years Leeuwenhoek and others had observed spermatozoa in the semen of many animals, but their nature and function remained subjects of bitter dispute for nearly 200 years. They were variously thought of as structures arising from putrefaction or chemical action; as parasites or adventitious infusoria; as specialized bodies whose function was merely to stir the semen or to arouse sexual desire in the male; and as the seed from which the future embryo would grow. Leeuwenhoek subscribed to the last of these views, and believed that spermatozoa developed into embryos after nidation within the egg. Spallanzani, however, concluded from his ingenious experiments in 1780 that spermatozoa did not play a vital role in reproduction; he considered that the seminal plasma was the agent that stimulated the egg to development. This was refuted by Prévost and Dumas in 1824; they showed that fertilization is a function of the spermatozoa. In 1841 Kölliker clearly demonstrated that spermatozoa are a normal and characteristic product of the testis and that they arise by proliferation and differentiation from the testicular tissue. Proof that spermatozoa are cells, consisting of nucleus and cytoplasm, was brought forward 24 years later by Schweigger-Seidel and La Valette St George. In 1843 Barry recorded the presence of spermatozoa within the rabbit egg, and then Nelson and Newport described the actual entry of spermatozoa into the eggs of the frog and the nematode *Ascaris*. Van Beneden in 1875, and Hertwig in 1876, gave the first clear accounts of the union between a nucleus formed from the spermatozoon and the egg nucleus; they maintained that this union was the cardinal feature of fertilization. Within a few years Flemming identi-

fied the chromosomes and described the process of mitosis. By 1890 the maturation of the gametes, fertilization, and the role of chromosomes were understood in principle and also in some detail.

The microscopes available to Leeuwenhoek and his contemporaries were crude by modern standards, and in consequence the early pictures of spermatozoa were often bizarre (figure 6), but sometimes remarkably good in view of the equipment used. Some observers reported that they could see alimentary tracts (figure 1), and other organs in spermatozoa, and even described and portrayed complete diminutive embryos or homunculi (figure 2). By 1890 the conventional light microscope had reached a state of development that can scarcely be bettered today, and painstaking investigations of spermatozoon morphology were undertaken, notably by Ballowitz and by Retzius (figures 3-5). In recent years, knowledge of the nature and functions of spermatozoa has grown rapidly through the development of new methods of microscopy (ultraviolet, electron, phase-contrast, interference-contrast, and fluorescence), of histochemistry, and of experimental biology in general.

MORPHOLOGY AND PHYSIOLOGY

The function of the spermatozoon is to initiate the development of the egg and to supply the paternal hereditary material, and perhaps other important or essential components, to the new embryo. In order to achieve this the spermatozoon must, of course, first reach and enter the egg. With so formidable a task to perform it is not surprising that the spermatozoon is a complex and highly specialized cell. It arises in the tubules of the testis, from a spermatozoon mother cell, as the result of a process of cell division and differentiation, during which the chromosome number characteristic of the species is reduced by half.

The mature spermatozoon is a small, very

condensed cell made up of two major parts, the head and the tail. Its refractive index suggests that only about 50 per cent of it is water [3] (by contrast, water constitutes 80-90 per cent of most cells). The volume of the bull spermatozoon is only about one twenty-thousandth of that of the egg, to which it is equivalent in hereditary significance. Unlike eggs, spermatozoa are produced in prodigious numbers: an average ejaculate of bull semen contains about five thousand million spermatozoa, which is sufficient to inseminate successfully at least 500 cows.

The nucleus. The principal component of the head is the nucleus (figures 51 and 52). This is composed of densely packed chromatin which is extremely difficult to disintegrate by physical means; it gives the characteristic staining reactions for deoxyribonucleic acid (DNA) and strongly absorbs ultraviolet radiation (figures 36-41). In bull spermatozoa about 43 per cent of the chromatin is DNA [16]. The remaining 57 per cent is protein, of which half is said to consist of the amino acid arginine. The DNA present in the spermatozoon nucleus is equal in amount to half that of a normal somatic nucleus of the species concerned, and it is now believed that the genetic information carried by the spermatozoon is in some way stored in the structure of the DNA molecules. The chromatin appears to be more densely aggregated in the posterior part of the nucleus, but is otherwise homogeneous in distribution: even electron microscopy of very thin sections (0.02μ) of spermatozoon nuclei has so far failed to reveal the presence of chromosomes.

In mammals the hereditary properties of the spermatozoon nucleus include the determination of the sex of the embryo. The X- and Y-chromosomes, which occur together in the somatic cells of male mammals, are separated during the development of the spermatozoon and two kinds of spermatozoa are formed: those that carry the X-chromosome initiate the development of female embryos, and those that carry the Y-chromosome initiate the development of male embryos. Many attempts have been made to identify X and Y spermatozoa by measurement of nuclear size and to separate them by physical and chemical means, but it is doubtful whether any success has ever been achieved. Attempts have also been made to destroy the chromatin of spermatozoa by X-irradiation or chemical treatment while leaving the spermatozoon otherwise unimpaired. Such spermatozoa might be capable of initiating the development of embryos even though they trans-

mit no active genetic material. Embryos produced in this manner would be females, but although the method is effective in certain amphibia it has not so far been successful in mammals.

In the spermatozoa of some rodents a slender process, the rod, extends from the nucleus to the apex of the hook-shaped head (figures 48 and 52). The rod, which contains no DNA, appears to be a thickened extension of the nuclear membrane [10]. It may function as a supporting structure for the acrosome (see below), but it is not found in the spermatozoa of microtine rodents [13], such as the field vole, which also have hook-shaped heads, and its significance is not clear.

The acrosome. The final stages of spermatogenesis involve the differentiation of the spermatid into the spermatozoon. During this process the Golgi apparatus of the spermatid is concerned with the formation of a cap-like structure, the acrosome, over the anterior surface of the nucleus. In mature spermatozoa the acrosome varies greatly in size and shape between different species, but its universal occurrence on the leading surface of the cell has for many years suggested that it plays a vital role in the penetration of the barriers that surround the egg. Many early workers believed that the acrosome had the function of mechanically piercing the egg membranes, and the sickle-shaped heads of some rodent spermatozoa lent themselves well to this interpretation. The hypothesis of simple mechanical function has, however, been long since rejected, and the acrosome is now regarded as probably providing a surface that is capable of attachment to the egg and of yielding enzymes that enable the spermatozoon to enter the egg. Evidence for these processes is still incomplete in mammals, but analogous functions of the acrosome have been demonstrated in the spermatozoa of certain invertebrates [11]. One indication that the mammalian acrosome plays a vital role in conception is that bull spermatozoa with an hereditary deformity of this structure (figure 55), but otherwise normal, are completely sterile [14].

From various lines of evidence, but particularly from studies of spermatogenesis, it seems that the acrosome is a double structure consisting of inner and outer caps (figures 51, 52, and 54). The two caps differ slightly in their staining reactions, but both give a positive reaction with the periodic acid Schiff (PAS) technique (figure 49) and for this reason are presumed to contain polysaccharide, possibly in the form of mucopolysaccharide. The acrosome also reacts characteristically with

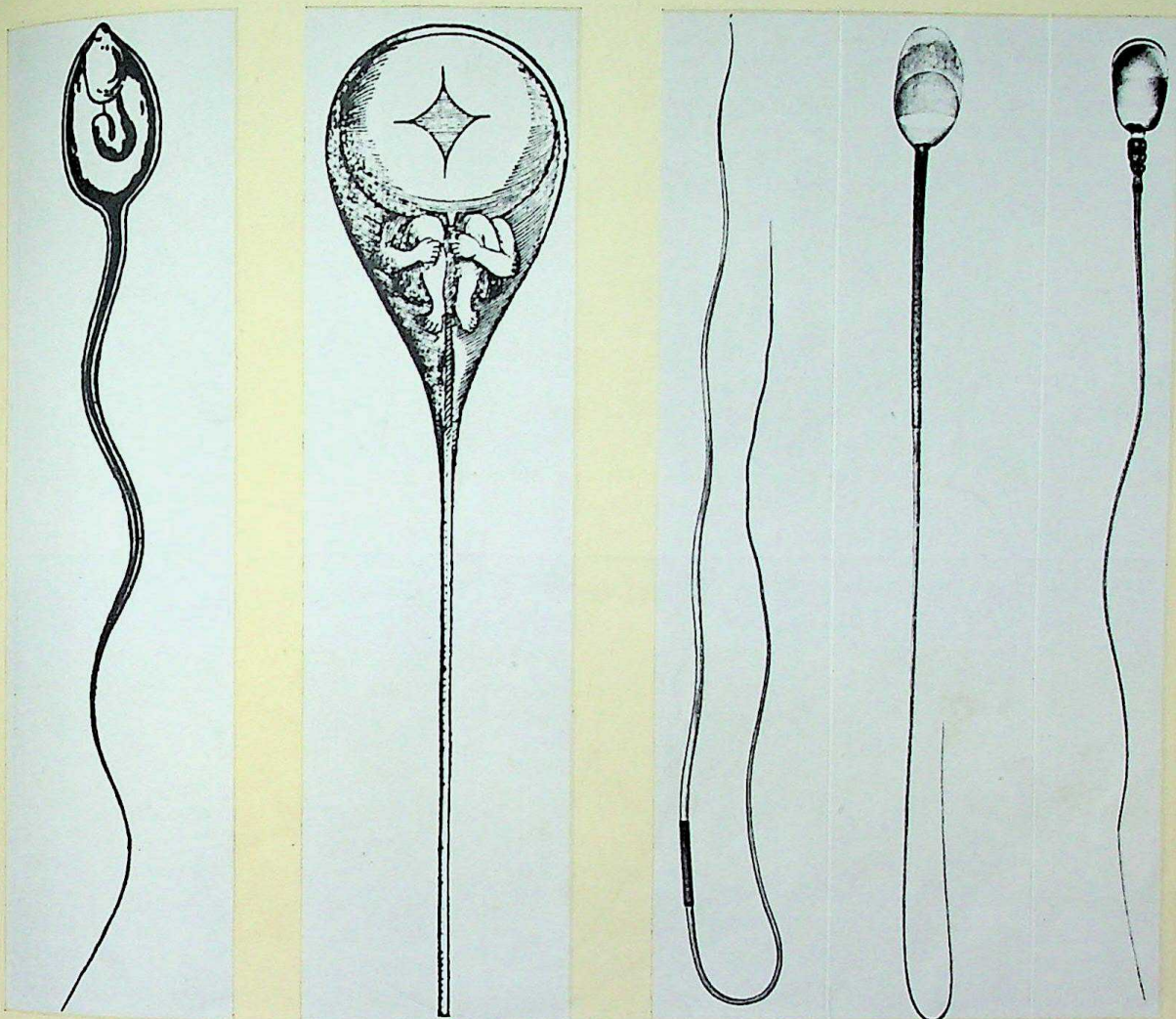


FIGURE 1 (Above, left) – Pouchet's picture (retouched) of the human spermatozoon. The head was believed to contain a simple alimentary tract. (From *Théorie positive de l'ovulation spontanée, et de la fécondation des mammifères et de l'espèce humaine*, Paris. 1847.)

FIGURE 2 (Above, right) – Human spermatozoon as conceived by Hartsoeker, showing an homunculus seated in the head. The spermatozoon tail was thought to contain the umbilical cord. (From *Essay de dioptrique*, Paris. 1694.)

FIGURES 3-5 – Retzius' pictures (1906 and 1909) of the spermatozoa of the Australian spiny ant-eater, the common European mole, and the pilot whale respectively. (Biol. Untersuch., N.F., 13 and 14.)

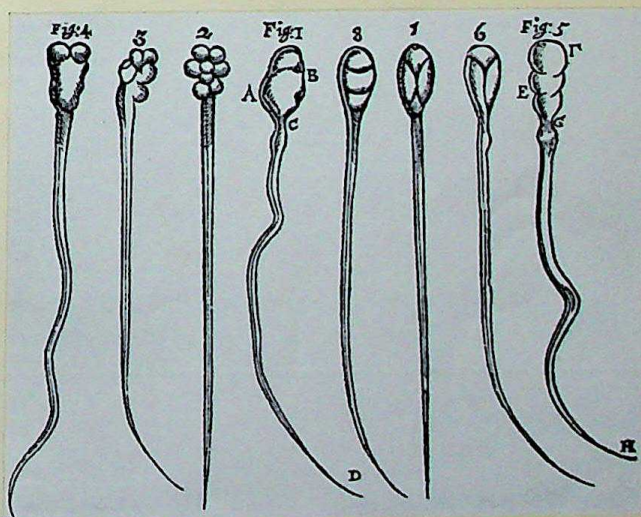
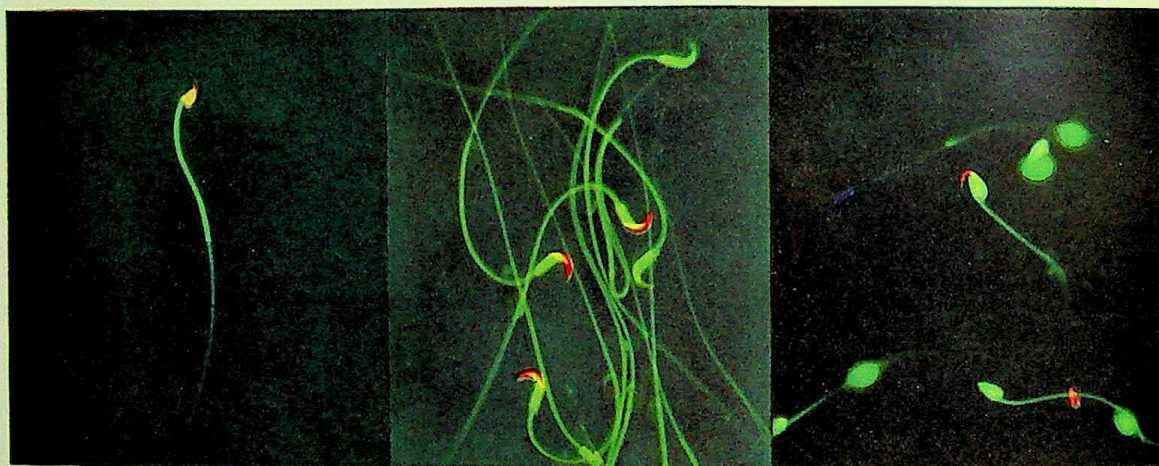
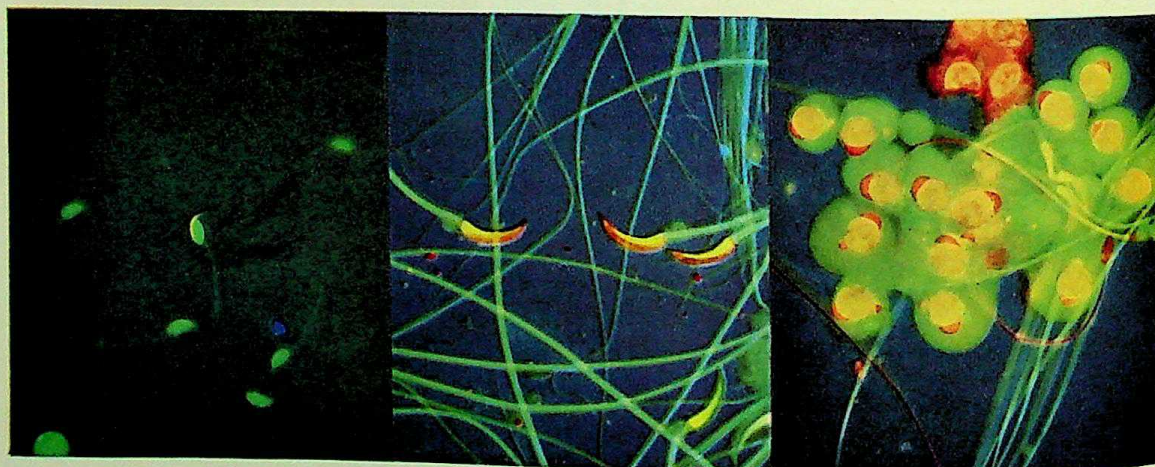


FIGURE 6 – Spermatozoa of the rabbit (Nos. 1-4) and dog (Nos. 5-8), as portrayed by Leeuwenhoek. (Phil. Trans., 12, 1040, 1679.)

FIGURE 7 - *Cotton rat.*FIGURE 8 - *Albino rat.*FIGURE 9 - *Rabbit.*FIGURE 10 - *Libyan jird.*FIGURE 11 - *Golden hamster.*FIGURE 12 - *Field vole.*FIGURE 13 - *House mouse.*FIGURE 14 - *Chinese hamster.*FIGURE 15 - *Chinese hamster spermatids.*

FIGURES 7-15 - *Living mammalian spermatozoa and spermatids treated with acridine orange and photographed in ultra-violet radiation. ($\times 660$)*

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Giemsa's stain, often displaying a segment of lighter colour posteriorly (figures 42-45). This is called the equatorial segment, and is believed to represent the region in which the outer acrosome cap overlaps the inner one [15]. The posterior border of the outer acrosome cap also corresponds to the anterior border of the post-nuclear cap, a cytoplasmic sheath covering the posterior part of the nuclear surface which can be demonstrated by its argentophil properties (figures 46 and 47).

Recent developments in fluorescence microscopy have greatly facilitated the study of the acrosome in living spermatozoa [7]. The technique is simple: the spermatozoa are treated with a low concentration of acridine orange and then examined in ultraviolet radiation. Under these conditions the acrosomes of fresh, living spermatozoa are seen as brilliant red fluorescent images where they extend beyond the nucleus, and as yellow or yellowish-green images where they overlap the nucleus (figures 7-14 and 16). The nuclei, where not covered by the acrosome, appear bright green. The method gives spectacular results with rodent spermatozoa, especially those with large acrosomes, but is less successful with rabbit and bull spermatozoa, in which the acrosome is rather small. The significance of the polychromatic fluorescence obtained is not yet established, but recent work in which similar techniques have been used on other kinds of tissue has shown that structures containing DNA fluoresce green with acridine orange, while those containing ribonucleic acid (RNA) fluoresce red [1, 4]. It is, however, very unlikely that the acrosome contains appreciable amounts of RNA, for it cannot be stained with pyronine [12] and shows negligible absorption of ultraviolet radiation (figures 36-41). Furthermore, chemical analysis of mature spermatozoa reveals that they are remarkable for their lack of RNA [5], a deficiency that might be expected to limit their synthetic abilities. One property of the material responsible for the red fluorescence of the acrosome is, however, fairly clear. This is the ease with which it leaves spermatozoa that are washed, dried, or stored *in vitro* at room temperature (compare figures 16 and 17). Loss of this material may explain the variable results often obtained with more conventional methods of differentiating the acrosome. Ability of the acrosome to exhibit red fluorescence is also lost in the female genital tract; this occurs before the death of the spermatozoon and may be associated with loss of fertility.

Whereas the spermatozoon as a whole is

remarkably resistant to distortion and disintegration, the acrosome is a relatively fragile structure and quickly shows degenerative changes when subjected to unfavourable conditions. These changes have often misled investigators in their interpretation of normal structure.

The tail and motility. The tail is the propulsive unit of the spermatozoon and pushes the cell along by the propagation of two-dimensional waves of bending, which pass distally along its length. It is a long (40-250 μ) flagellum, differentiated into four regions, the neck, the mid-piece, the main-piece, and the end-piece. During development, the rudiment of the tail arises as a slender filament from the spermatid centrioles and even at a very early stage exhibits undulating movements that appear to be initiated from the centrioles.

The neck is the short anterior extremity of the tail; very little is known of its detailed structure. Attached to the neck, but apparently embedded in the base of the nucleus, are the basal granules. By some techniques three granules are demonstrable in this region (figure 44), by others only two (figure 50). Possible explanations are that there are in fact three granules, of which two differ in their properties from the third, or else that the number differs in different species. Fluorescence microscopy with rhodamin shows two granules in the base of the head of motile rodent spermatozoa, but when the spermatozoa lose their motility the granules fail to fluoresce [7].

An axial core of twenty discrete fibres runs from the neck throughout the tail. The existence of such fibres has been known for almost 70 years, but their number and precise disposition within the tail have only recently been revealed by electron microscopy. It is now known that the axial core consists of two central fibres surrounded by nine fibres of similar diameter. These in turn are surrounded by a further ring of nine thicker fibres (figures 56 and 58) [9]. Available evidence indicates that the fibres pass straight along the tail and are not twisted about its axis. They appear to be gathered into three, or perhaps only two, bundles in the neck.

The mid-piece is characterized by a double mitochondrial helix surrounding the axial core. This helix can just be resolved by ultraviolet microscopy and is clearly demonstrable by electron microscopy (figure 57). It is formed by aggregation of mitochondria from the spermatid.

The main-piece is the longest part of the tail and provides most of the propellant machinery. Here the axial core is surrounded by a tough

helical protein sheath, down either side of which runs a small rib [9]. It bears no mitochondria.

The tail ends in a short (3–10 μ) distal endpiece, which is not surrounded by a helical sheath.

The possible mechanism by which the tail produces its characteristic movement has recently been discussed by J. R. G. Bradfield [9]. By virtue of their size and position, the nine fibres of the outer ring are thought to be the main contractile elements and to be capable of propagating localized contractions along their length. The helical protein sheath, together with an inter-fibre matrix, probably provide the skeletal structure against which the contractile fibres can work. The inner fibres may be specialized for the rapid conduction of impulses, arising rhythmically in the neck, which co-ordinate the localized contractions in the outer fibres. It may be noted in passing, however, that a simpler explanation could be advanced if the fibres were twisted about the axis of the tail instead of running straight as is at present believed. There is no evidence of contractile apparatus in the mitochondria, and it is likely that they are concerned solely with the provision of energy. Indeed, in view of the known localization of enzyme systems within mitochondria, and the role that these organellae play in the formation of high-energy phosphate compounds, the mid-piece is regarded as the main power house of the spermatozoon, though glycolytic enzymes may be distributed throughout the inter-fibre matrix. It is known that the tail contains all the apparatus necessary for motility, for tails that have been separated from heads can be fully motile.

Spermatozoa remain quiescent while within the epididymis but become actively motile at ejaculation (or when removed from the epididymis). The principal activating factor appears to be the increased availability of oxygen. The transulatory speed of movement *in vitro* varies with the nature of the medium and with temperature, and is of the order of 100 μ per second at body temperature. Spermatozoa tend to orientate themselves against a current, for this is their position of greatest mechanical stability. On the other hand, there is no evidence that the direction of swimming is influenced by chemical gradients, and this suggests that the approach of the mammalian spermatozoon to the egg is not aided by chemotaxis.

One might suppose that the purpose of motility was to enable the spermatozoon to ascend the female genital tract to the site of fertilization in the Fallopian tubes, but this does not appear to be so, for in several species it is known that sper-

matozoa reach this site much more rapidly than they could by their own motility. Transport through the tract is almost certainly attributable to the muscular contractions of the walls of the tract and to currents produced by cilia that line these walls. The major function of motility, therefore, seems to be to assist the spermatozoon to penetrate the barriers surrounding the egg.

The cytoplasmic droplet. Most of the spermatid cytoplasm is eliminated from the cell during spermatogenesis, but a small bead, the cytoplasmic droplet, remains for a while attached to the neck of the spermatozoon. While passing through the epididymis the droplet migrates from the neck to the distal end of the mid-piece, and at the same time the spermatozoon develops its potentiality for motility and fertility. At ejaculation the droplet usually becomes detached.

The function of the cytoplasmic droplet remains one of the chief enigmas in the story of the spermatozoon. Its invariable presence on spermatozoa when released from the testis, its characteristic size and shape, and its ordered migration along the mid-piece signify that it is not merely a casual remnant of unwanted material. Its loss from the spermatozoon at the time of ejaculation, however, shows that its function must be concerned solely with the physiology of the spermatozoon within the male tract. This suggests that it may be involved in maturation processes or in the maintenance of the cell in a quiescent state and for a very much longer period than can be achieved at a similar temperature outside the epididymis.

The surface membrane. The surface membrane of the spermatozoon is composed of a lipid-protein complex, and phospholipids can be easily removed from it by washing in saline. The surface of the head, or perhaps only the part that is covered by the acrosome, is serologically distinct from the surface of the tail, and this difference is probably significant in fertilization. When the cell dies, the permeability of the membrane becomes greatly increased, and advantage has been taken of this to devise staining techniques that will distinguish living spermatozoa from dead ones (figure 18). The surface of the dead cell also has a high affinity for glass, and living spermatozoa can readily be separated from dead ones by filtration through a bed of fine glass beads [2].

Species differences in size and shape. Although mammalian spermatozoa are all constructed on a common pattern, the spermatozoa of each species display differences of shape and proportion that are quite characteristic. It is possible, indeed, to

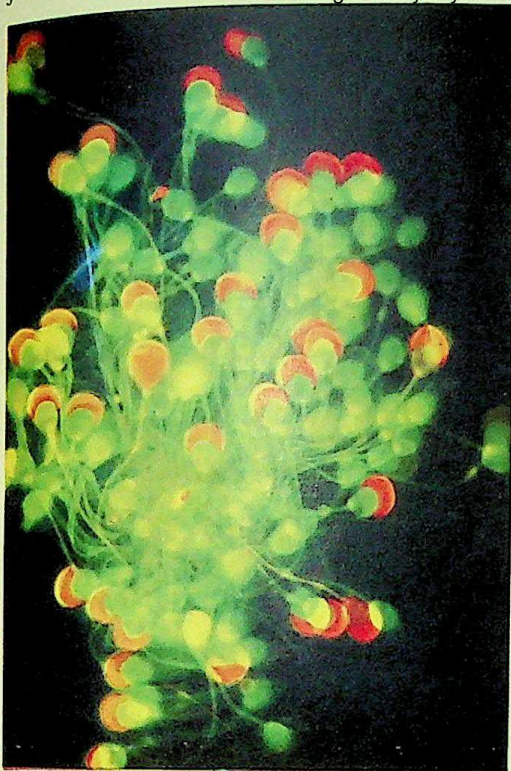


Figure 16

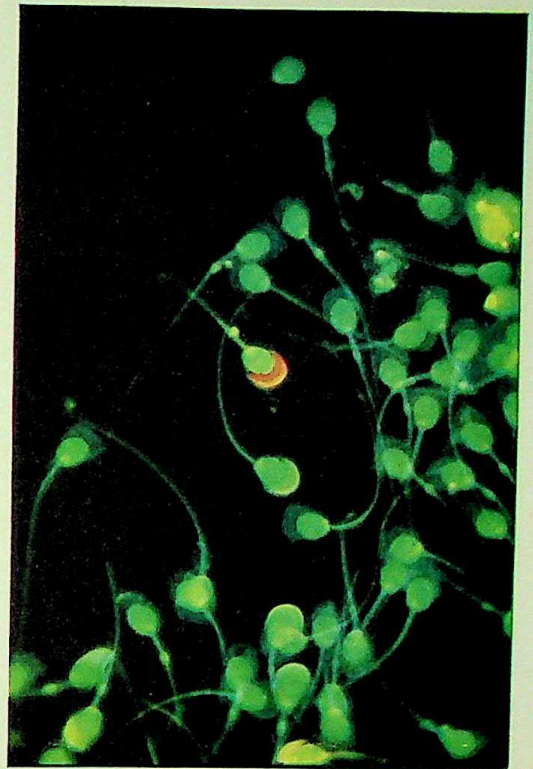


Figure 17

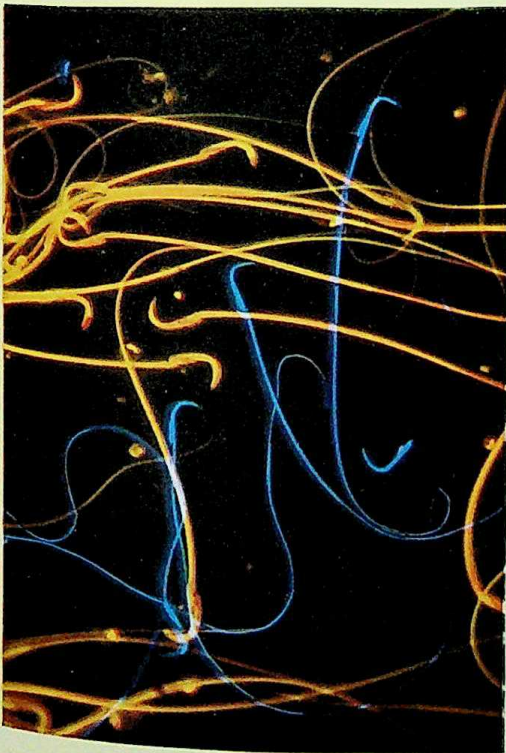


Figure 18

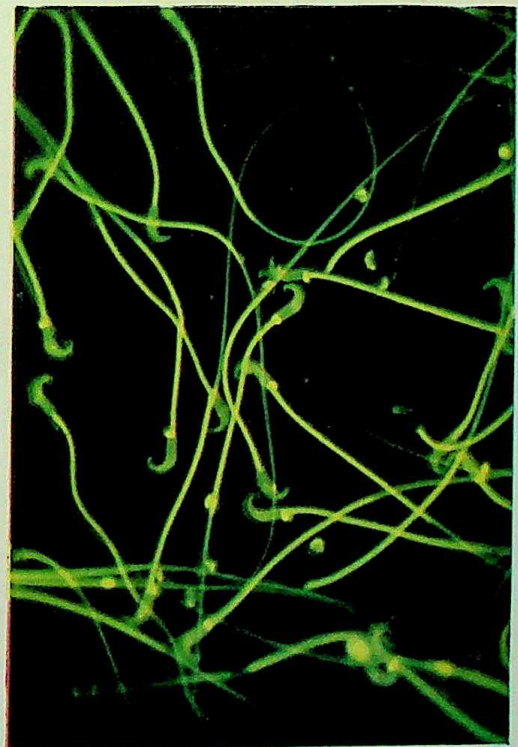


Figure 19

FIGURES 16 AND 17 – Guinea-pig spermatozoa fluorescing in ultraviolet radiation after treatment with acridine orange. Those shown in figure 16 were photographed soon after collection; those in figure 17 had previously been kept for some time in vitro. ($\times 660$)

FIGURE 18 – The different fluorescence exhibited by living (yellow) and dead (blue) rat spermatozoa when treated with a mixture of primulin and rhodamin B and examined in ultraviolet radiation. ($\times 660$)

FIGURE 19 – Spermatozoa of the golden hamster treated with rhodamin 6G and examined in ultraviolet radiation. The fluorescent bodies at the base of the heads are interpreted as being the basal granules. ($\times 660$)

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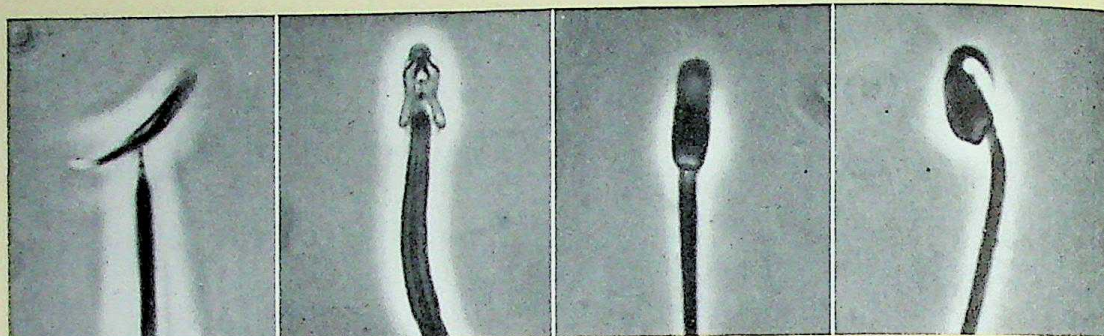


FIGURE 20 - *Tiger cat.* FIGURE 21 - *Long-nosed bandicoot.* FIGURE 22 - *Greater horseshoe bat.* FIGURE 23 - *Field vole.*

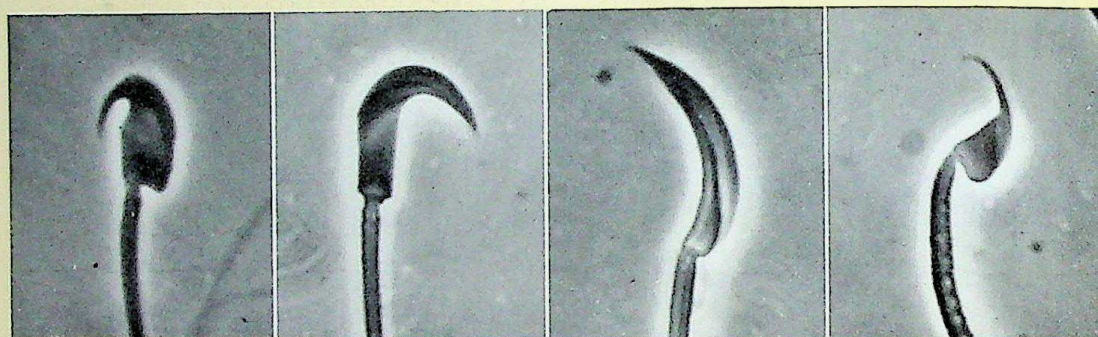


FIGURE 24 - *Cotton rat.* FIGURE 25 - *Golden hamster.* FIGURE 26 - *Chinese hamster.* FIGURE 27 - *Libyan jird.*

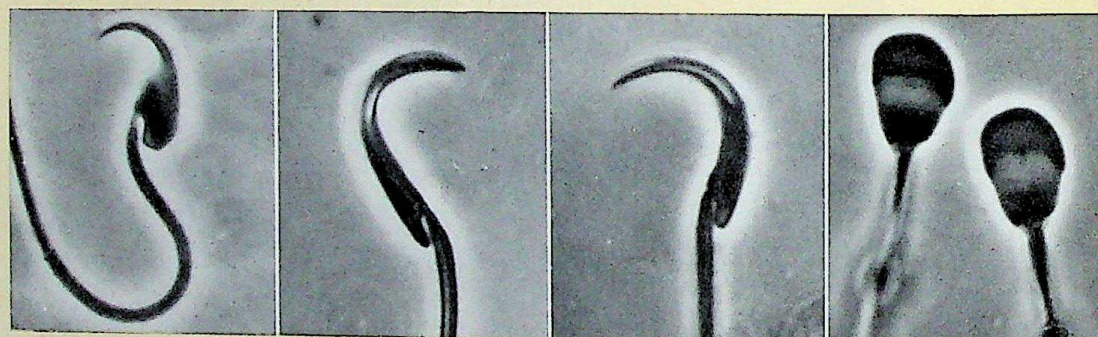


FIGURE 28 - *Barbary striped mouse.* FIGURE 29 - *Albino rat.* FIGURE 30 - *Multi-mammate rat.* FIGURE 31 - *Ferret.*

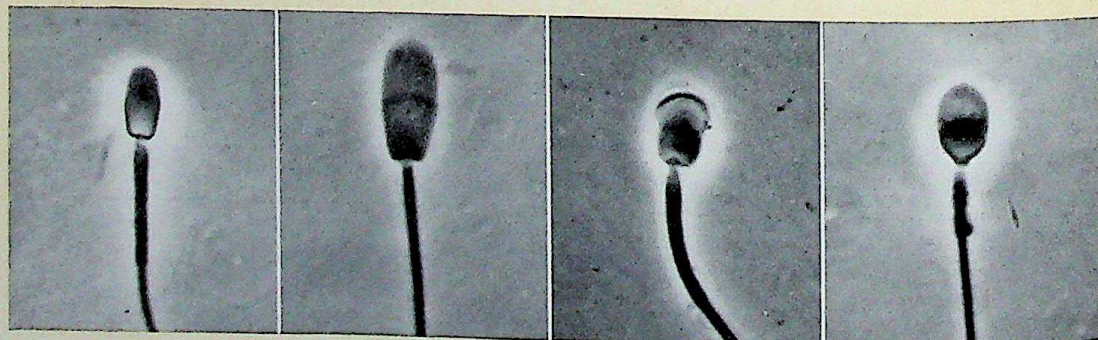
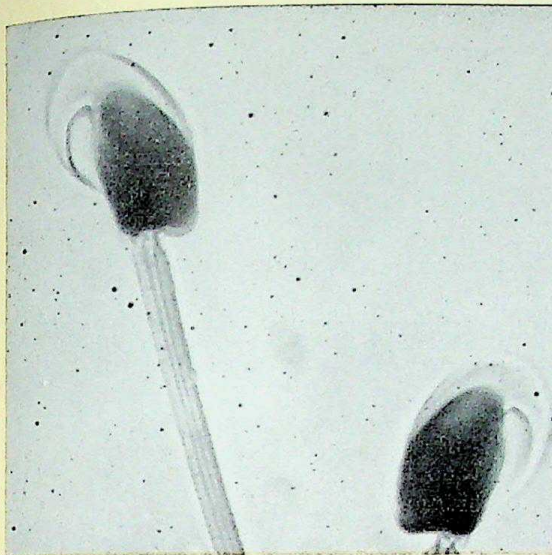
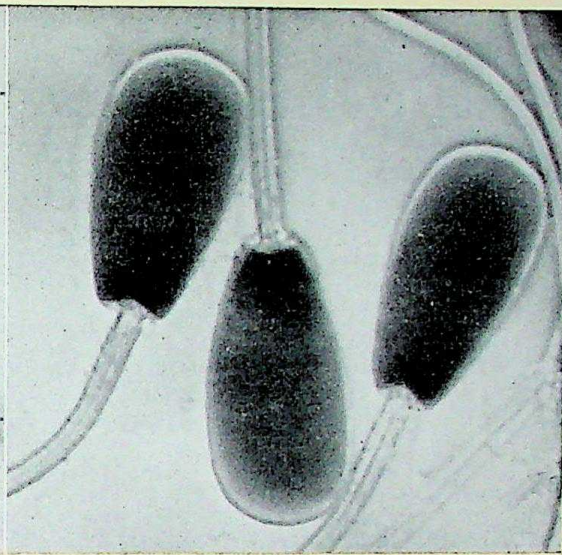
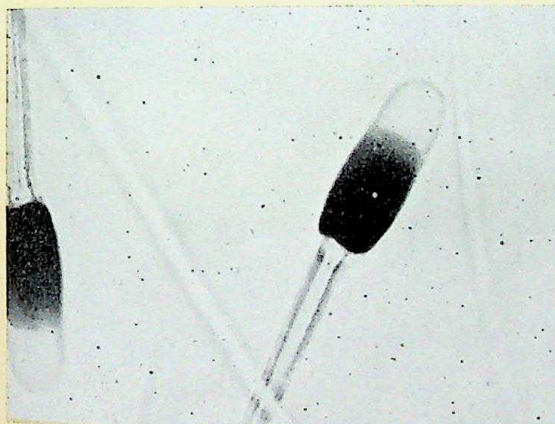
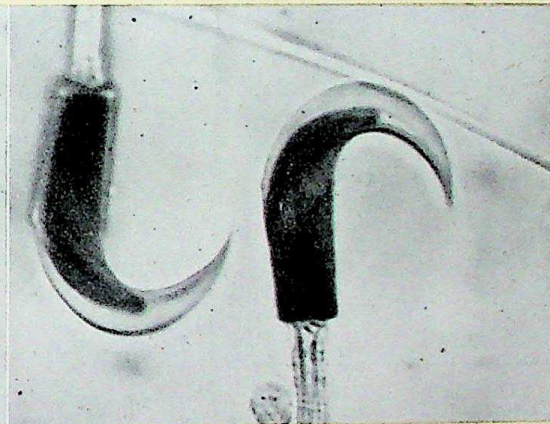
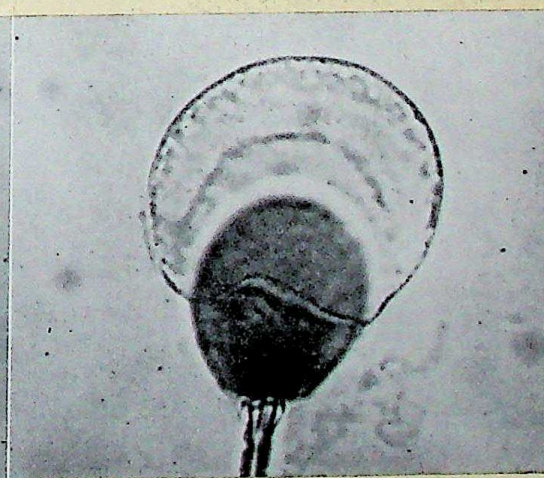


FIGURE 32 - *Cat.* FIGURE 33 - *Goat.* FIGURE 34 - *Greater bush-baby.* FIGURE 35 - *Man.*

FIGURES 20-35 - *The heads of living mammalian spermatozoa as seen by phase-contrast microscopy. ($\times 2000$)*

FIGURE 36 - *Cotton rat.*FIGURE 37 - *Bull.*FIGURE 38 - *Greater horseshoe bat.*FIGURE 39 - *Golden hamster.*FIGURE 40 - *Albino rat.*FIGURE 41 - *Guinea-pig.*

FIGURES 36-41 - Ultraviolet photomicrographs of the heads of living mammalian spermatozoa, showing the strong absorption of radiation by the nucleic acid in the nucleus. ($\times 4000$ approx.) (Figure 37 from J. exp. Biol., 29, 445, 1952.)



FIGURE 42 - Golden hamster
(Giemsa; $\times 2900$).

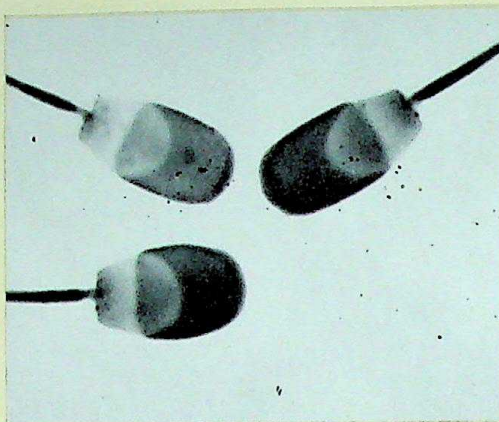


FIGURE 43 - Boar (Giemsa; $\times 2800$).

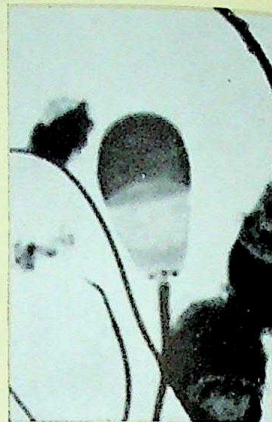


FIGURE 44 - Bull
(Giemsa; $\times 2400$).



FIGURE 45 - Guinea-pig
(Giemsa; $\times 2200$).

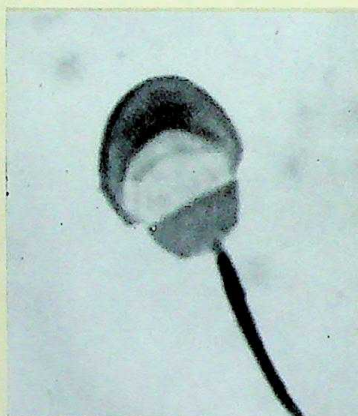


FIGURE 46 - Guinea-pig
(silver impregnation; $\times 2200$).



FIGURE 47 - Bull
(silver impregnation; $\times 2400$).

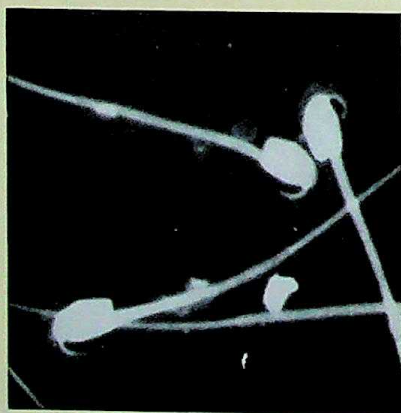


FIGURE 48 - Cotton rat
(primulin; $\times 1400$).



FIGURE 49 - Boar
(PAS; $\times 2800$).



FIGURE 50 - House mouse
(rhodamin 6G; $\times 1200$).

FIGURES 42-50 - Photomicrographs of stained preparations of mammalian spermatozoa, demonstrating the acrosome, the rod, the equatorial segment, the post-nuclear cap, and the basal granules. (Figure 49 in press, J. R. micr. Soc.)

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identify an animal merely by examining its spermatozoa. The overall size of the cell, though characteristic for each species, does not vary very greatly between species and is quite unrelated to the size of the animal concerned, but interspecific differences in the sizes of head and mid-piece relative to the whole spermatozoon are particularly notable. The projected area of the head of the guinea-pig spermatozoon, for instance, is nearly five times larger than that of the human, though the length of the guinea-pig spermatozoon is only about twice as great as the human. The mid-piece of the rat spermatozoon constitutes about 40 per cent of the total length of the tail, while that of the human spermatozoon amounts to no more than 10 per cent (compare also figures 4 and 5). Even more striking are the differences in the shape of the head. In most large animals the head is a more or less oval and flattened structure. In man (figure 35) it is oval in plan view but pear-shaped in sagittal section. In many rodents (figures 23-30) it is asymmetrical and often hook-shaped. In many marsupials the head is deeply invaginated at the posterior end (figure 21), but in some it is more rod-like in form (figure 20); the head appears to be pivoted at the point of insertion of the neck. The spermatozoa of the egg-laying monotremes (figure 3) have long, narrow vermiform heads and resemble the spermatozoa of birds more than those of mammals. It is not known whether there is any adaptive significance in the differences of shape between species. Differences of head shape between strains within a species have also been demonstrated for spermatozoa of the mouse [8].

Metabolism and survival. It was formerly believed that mammalian spermatozoa were incapable of utilizing extracellular nutrient and that the limit of their independent existence was determined by the intracellular food reserves acquired during spermatogenesis. It is now well known, however, that these cells can metabolize a number of extracellular substrates and use the energy so obtained to maintain their physiological functions. Chief of the energy-providing systems available to mammalian spermatozoa are the Embden-Meyerhof glycolytic system, by which fructose and glucose can be broken down to lactic acid, and the cytochrome oxidase-cytochrome system and Krebs cycle, by which a variety of substrates, but notably lactate and pyruvate, can be oxidized to carbon dioxide and water. Even in the absence of exogenous substrate, mammalian spermatozoa can respire actively and maintain their motility for an

appreciable time. Under these conditions it is believed that they obtain energy by the oxidation of endogenous phospholipid, a characteristic component of mitochondria, in a manner closely analogous to the normal metabolism of sea-urchin spermatozoa [19]. It is believed that the oxidative enzymes are all located within the mitochondria, but the Embden-Meyerhof enzymes are generally regarded as being cytoplasmic in distribution and are therefore probably more widely spread throughout the cell. Glycolytic metabolism can take place under anaerobic conditions, but yields much less energy than aerobic oxidation.

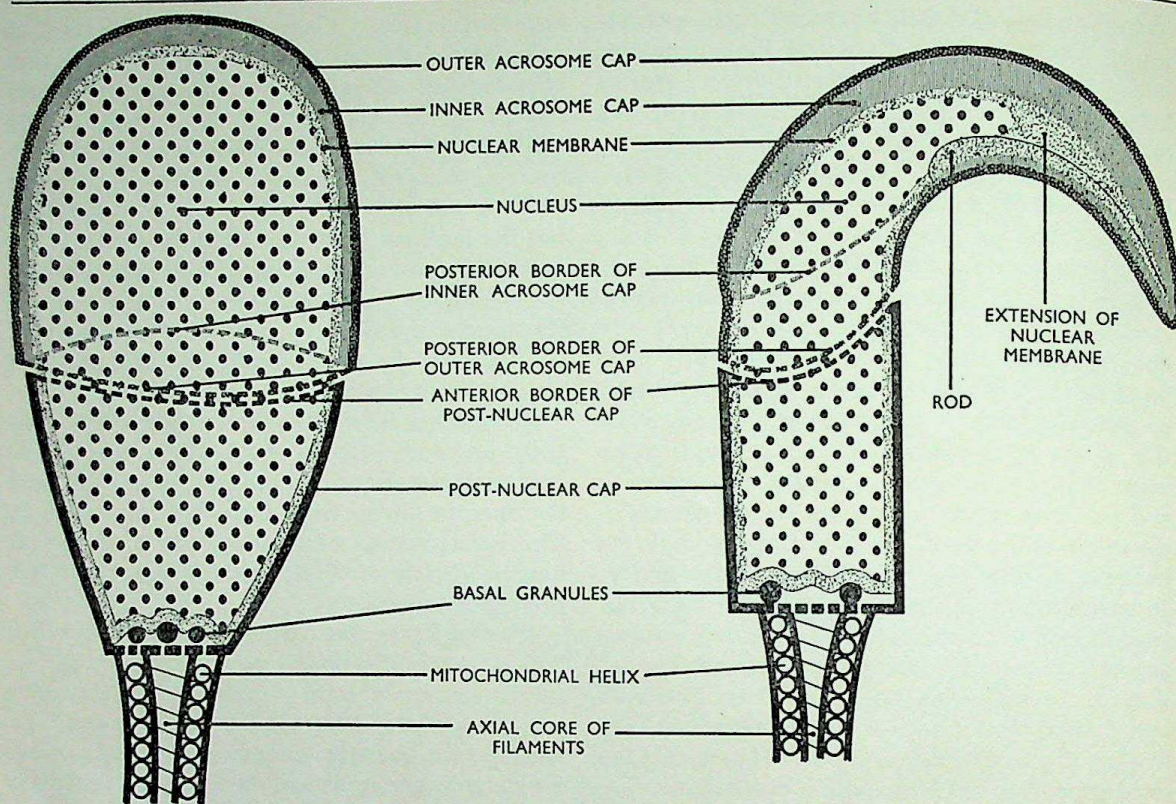
Metabolism is not, however, restricted to catabolic processes. Recent work shows that mammalian spermatozoa synthesize lipids [17] and incorporate amino acids into their proteins [5]. The incorporation of amino acids is of special interest in view of the apparent absence of RNA from spermatozoa.

It seems likely that aerobic oxidation plays the dominant role in spermatozoon metabolism within the female reproductive tract, because both oxygen and lactate are available in this situation. In most species, however, spermatozoa do not survive for more than one or two days within the female tract, though some bats provide notable exceptions to this. Within the epididymis, spermatozoa appear to exist under conditions in which both oxygen and glycolysable sugar are deficient; nothing is known of their metabolism in this location, but metabolic activity is probably low. Here they retain their fertility for one or two months and their potential for motility for rather longer. They survive for only a short time *in vitro* at body and room temperatures, but survival time can be prolonged by reducing the temperature of storage. By dilution with suitable media and careful cooling, the fertility of bull spermatozoa can be preserved for several days at 4°C and for years at -79°C [18].

THE SPERMATOZOON IN FERTILIZATION

In order to enter the egg the spermatozoon must pass through three barriers. These are the thin vitelline membrane which encloses the protoplasm of the egg proper; the thick (10-12 μ) mucoproteinous zona pellucida; and several layers of follicle cells which adhere to the zona pellucida and are embedded in a gelatinous matrix composed largely of hyaluronic acid.

Spermatozoa pass between the layers of follicle cells, traversing the matrix with the aid of hyaluronidase, an enzyme that can be very easily



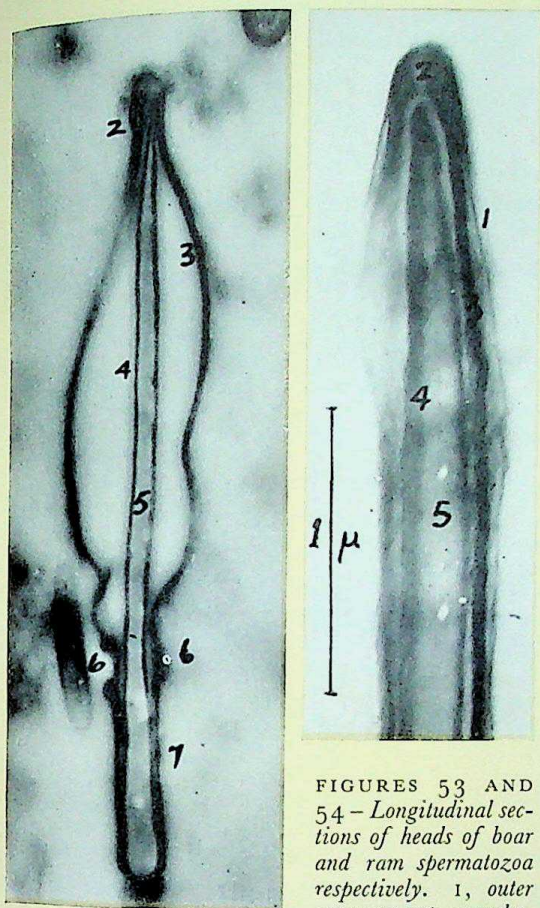
FIGURES 51 AND 52 - Diagrammatic representation of the probable structure of the heads of bull (left) and hamster (right) spermatozoa respectively.

extracted from mammalian spermatozoa. In the presence of large numbers of spermatozoa the follicle cells are quickly dispersed from the egg, but despite the hundreds of millions of spermatozoa that are released into the female tract at coitus only a few thousand attain the site of fertilization, and those that first reach the eggs are too few to denude them. Penetration of the egg occurs before dispersal of the follicle cells, which may in fact assist entry of the spermatozoon by increasing the target area, and by guiding spermatozoa toward the egg. Evidently the hyaluronidase associated with the individual spermatozoon is sufficient to enable it to make its way through the mass of follicle cells. It seems likely that the spermatozoon hyaluronidase is carried by the acrosome; it may in fact be associated with the labile material that exhibits a red fluorescence after treatment with acridine orange.

On reaching the zona pellucida, the spermatozoon becomes attached to its surface by the acrosome, and there is evidence that this attachment is made by an antigen-antibody type of reaction [6]. The spermatozoon then proceeds to penetrate the zona pellucida, presumably with the

aid of another enzyme also located within the acrosome. Attempts to extract this enzyme from mammalian spermatozoa have so far failed, but a small hole that remains in the zona pellucida after the passage of the spermatozoon testifies to its probable existence. A remarkable feature of this penetration, however, is that it cannot take place until the spermatozoa have remained for a short period within the female tract and have undergone some kind of preparatory change. The change is called capacitation; its nature is unknown, but is supposed to involve activation of the hypothetical enzyme within the acrosome. The need for capacitation probably explains the present failure to extract an active zona-pellucida lysin from spermatozoa and the difficulty of fertilizing mammalian eggs *in vitro*.

After penetrating the zona, the spermatozoon becomes attached to the vitelline membrane, and is then apparently slowly engulfed by the cytoplasmic part of the egg. First the spermatozoon head, and then the tail, sink slowly into the egg cytoplasm. This entry is associated with the stimulation of the egg to development and with changes in the vitelline membrane and the zona



FIGURES 53 AND 54 - Longitudinal sections of heads of boar and ram spermatozoa respectively. 1, outer acrosome cap. 2 and 3, inner acrosome cap. 4, nuclear membrane. 5, nucleus. 6, junction of acrosome and post-nuclear cap. 7, post-nuclear cap. The separation between the acrosome and nucleus in figure 53 is an artefact. ($\times 13\ 000$ and $\times 38\ 000$ respectively.)

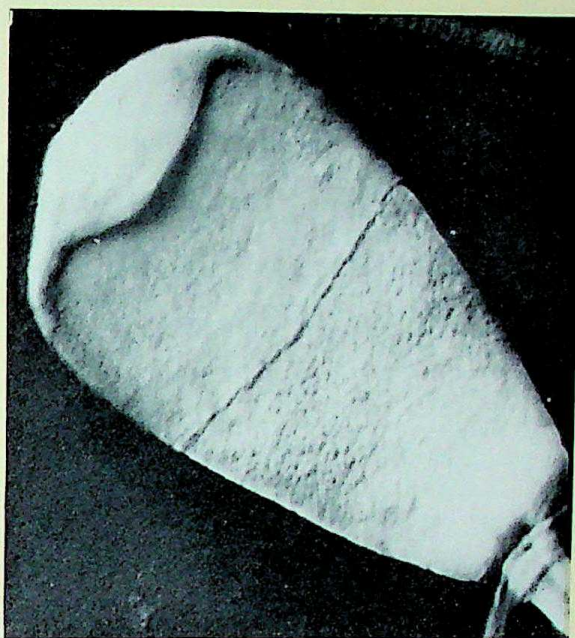


FIGURE 55 - Head of bull spermatozoon, showing an hereditary defect of the acrosome (gold-palladium shadowed; $\times 9000$).

FIGURE 56 (Right) - Transverse section of the mid-piece of the tail of a ram spermatozoon. ($\times 60\ 000$)

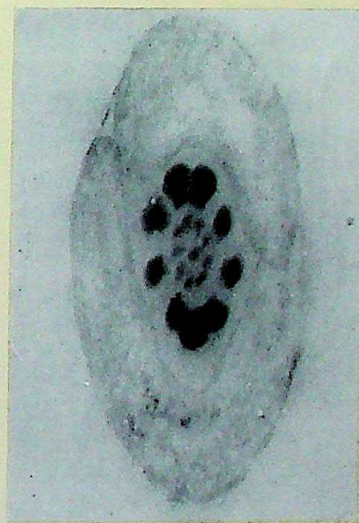


FIGURE 58 - Transverse section of the main-piece of the tail of a boar spermatozoon. The inner and outer rings of nine fibres and the two central fibres are not separately resolved in this photograph. ($\times 50\ 000$)

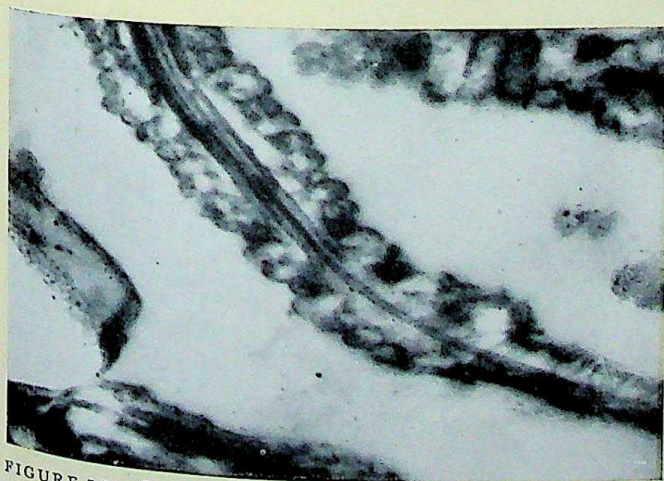


FIGURE 57 - Longitudinal section of part of the mid-piece and main-piece of the tail of a ram spermatozoon, showing the mitochondrial helix and the axial filaments. ($\times 20\ 000$)

FIGURES 53-58 - Electron micrographs of boar, bull, and ram spermatozoa. (Figure 55 [14]; figure 56 [9].) CC-0. In Public Domain. Gurukul Kangri Collection, Haridwar

pellucida that render these membranes impenetrable to further spermatozoa. The membrane changes reduce the danger of fertilization by more than one spermatozoon, an event that seems to be incompatible with survival of the resulting embryo.

Inside the egg the spermatozoon nucleus increases greatly in size and loses its characteristic shape. The nucleus then moves towards the centre of the egg, as does a similar nucleus produced by the egg. The two nuclei come into close contact, the nuclear membranes disappear, and the nuclei are replaced by two chromosome groups, which come together to form a single group. This marks the end of fertilization and the beginning of the first cleavage mitosis of the new embryo. The union of the two haploid chromosome groups re-establishes the diploid number of the species. When the egg divides, each chromosome duplicates itself and each daughter cell receives an equal share of the chromosomes supplied by the spermatozoon and by the egg.

Since as a general rule the entire spermatozoon enters the egg, it is possible that spermatozoon structures other than the nucleus may play an important part in the development of the new embryo. It has been suggested that the acrosome is responsible for stimulating the egg to active development, that spermatozoon centrioles play an essential role in the formation of the first cleavage spindle, and that mitochondria from the mid-piece remain functional within the egg cytoplasm.

As yet, however, there is little evidence for these processes in mammals.

APPENDIX

LIST OF SPECIES OF WHICH THE SPERMATOZOA ARE ILLUSTRATED

	Figure
MONOTREMATA	
Australian spiny anteater, <i>Tachyglossus aculeatus</i>	.. 3
MARSUPIALIA	
Tiger cat, <i>Dasyurus maculatus</i>	 20
Long-nosed bandicoot, <i>Perameles nasula</i>	 21
PLACENTALIA	
Common European mole, <i>Talpa europaea</i>	 4
Greater horseshoe bat, <i>Rhinolophus ferrum-equinum</i>	 22, 38
Greater bush-baby, <i>Galago crassicaudatus</i>	 34
Man, <i>Homo sapiens</i>	 35
Ferret, <i>Mustela furo</i>	 31
Cat, <i>Felis catus</i>	 32
Pilot whale, <i>Globicephalus melaena</i>	 5
Boar, <i>Sus scrofa</i>	 43, 49, 53, 58
Bull, <i>Bos taurus</i>	 37, 44, 47, 51, 55
Ram, <i>Ovis aries</i>	 54, 56, 57
Goat, <i>Capra hircus</i>	 33
Rabbit, <i>Oryctolagus cuniculus</i>	 9
Barbary striped mouse, <i>Lemniscomys barbarus</i>	 28
Albino rat, <i>Rattus norvegicus</i>	 8, 18, 29, 40
Multimammate rat, <i>Mastomys coucha</i>	 30
House mouse, <i>Mus musculus</i>	 13, 50
Golden hamster, <i>Mesocricetus auratus</i>	 11, 19, 25, 39, 42, 52
Chinese hamster, <i>Cricetulus griseus</i>	 14, 15, 26
Cotton rat, <i>Sigmodon hispidus</i>	 7, 24, 36, 48
Libyan jird, <i>Meriones libycus</i>	 10, 27
Field vole, <i>Microtus agrestis</i>	 12, 23
Guinea-pig, <i>Cavia porcellus</i>	 16, 17, 41, 45, 46

ACKNOWLEDGMENTS

We are indebted to Mr J. Smiles for his invaluable assistance with problems of microscopy, to Mr M. R. Young for his skill in obtaining the ultraviolet and fluorescence photomicrographs of figures 7-19 and 36-41, to Dr J. L. Hancock for supplying some of the photomicrographs of

stained spermatozoa (figures 43, 44, 49), to Dr J. R. G. Bradfield for the electron micrographs (figures 53-58), and to Dr Adolph Bolliger, Professor E. C. Amoroso, and Mr Michael Blackmore for providing for study spermatozoa of marsupials, the cat, and the greater horseshoe bat respectively.

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Ferromagnetic domains

L. F. BATES

The physical processes involved when a ferromagnetic metal is magnetized have been the subject of much study. In this article are described some recent contributions to our knowledge of these processes that have been obtained by techniques which, though elaborate, are fundamentally no more than those familiar to every elementary student of magnetism and enable us to follow some of the processes in considerable detail.

INTRODUCTION

In this article will be described some interesting and important results obtained by a modern variant of the familiar experiment of plotting lines of magnetic force by means of iron filings. The striking magnetic properties of ferromagnetic substances like iron are currently attributed to special aligning forces, called exchange forces, between spinning electrons in neighbouring atoms. The main object of the present investigations is to obtain detailed information about what happens when a ferromagnetic substance is exposed to magnetizing influences, in order to test basic magnetic theories and to provide a logical basis for improving the performance of ferromagnetic materials. Since a polycrystalline material usually consists of a large number of very small crystals whose boundaries give rise to phenomena which, though very interesting, greatly complicate the experiments, most of the work has been confined to single-crystal specimens.

Let us first consider the magnetic behaviour of a single crystal of cobalt, as we have in this a very clear example of what is termed ferromagnetic crystalline anisotropy. The crystal may be represented as a hexagonal block, which at ordinary temperatures may be magnetized with ease in either of the two directions parallel to the axis of the block but only with some difficulty in any direction perpendicular to this, i.e. in the plane of the hexagon. Because of this property, the first two directions are called the directions of easy magnetization.

To account for the ease with which a demagnetized ferromagnetic metal may be magnetized almost to saturation by the application of a weak magnetic field, it is assumed that the metal consists of a very large number of elementary regions or domains, each magnetized to saturation, and the magnetic vector in each domain is considered to be parallel to a direction of easy magnetization in the crystal of which it forms a part. In the de-

magnetized specimen the magnetic vectors of the several domains must in general be randomly distributed or, in special cases, arranged in a closed configuration. Between domains there must then be a boundary or a narrow region of transition.

On the application of a magnetic field to a demagnetized crystal two main changes occur. Firstly, those domains whose magnetic vectors make an angle less than 90° with the applied field increase in size at the expense of their less favourably magnetized neighbours by what is termed boundary displacement. Secondly, the vectors of the individual domains tend to rotate in order to set as nearly as possible parallel to the field. The first change occurs mainly in low and moderate fields and the second in high fields, although they are frequently superimposed. In very strong fields all the vectors point along the field direction and the crystal is technically saturated, being in effect one large single domain.

EXPERIMENTAL TECHNIQUE

For such study a crystal must be carefully shaped and its surface properly prepared. It is usually given a good mechanical polish, and the amorphous, strained surface layer which results is later removed by electrolytic polishing in a special bath, using a simple bridge circuit [1] to control the current. Cobalt is one of the easiest metals to prepare for study in single-crystal form.

The polished surface is mounted horizontally, and upon it a drop of a colloidal solution of magnetite is placed or a very fine ferromagnetic powder is blown. The magnetite or powder particles form a pattern which may be viewed or photographed with a metallurgical microscope, using a magnification of between 50 and 400. Such patterns are known as powder patterns or Bitter figures [2]. The best results are normally obtained with colloidal magnetite solutions prepared according to W. C. Elmore's recipe [3, 4].

ENDEAVOUR

EXPERIMENTS WITH COBALT CRYSTALS

When we apply this technique to a strip from the face of a single crystal of cobalt cut parallel to the hexagonal axis, a pattern like that of figure 3 is obtained for the demagnetized state. The horizontal dark lines of colloid separate domains which are alternately magnetized along one or the other of the two directions of easy magnetization. The dagger-shaped figure in the right-hand portion of the picture is a closure domain, a subsidiary structure whose function is described below, and this is magnetized anti-parallel to the principal domain in which it lies. The serrated outline in the middle of the picture is very unusual, and is probably due to sub-surface damage to the crystal.

The heavy-line deposits occur because there is a 180° domain wall between two neighbouring domains. Now, ferromagnetism is attributed to exchange interaction between electron spins, and the electrons responsible for ferromagnetism in neighbouring domains must have their spin vectors aligned in opposite directions. Consequently, along a line of atoms running through the wall and perpendicular to it, the direction of electron spin must change continuously from atom to atom. This will be made manifest by an emergent stray field above the intersection of the domain wall with the crystal surface, and here magnetic dipoles in the colloid are attracted and attach themselves.

When a magnetic field is applied to the specimen shown in figure 3 in a direction parallel to the crystal axis, the specimen becomes magnetized by 180° boundary displacement. Alternate domains expand and contract sideways until the crystal becomes one large domain and all boundaries disappear. In figures 4 and 5 are seen the effects of applying a small magnetic field perpendicular to the surface. Since the surface is unlikely to be an exact crystal plane, it must have a small component of magnetization normal to the surface in each domain. This component will be either increased or decreased on the application of a weak perpendicular field. In figure 4 such a field runs into, and in figure 5 out of, the surface, and by using imperfections in the surface as reference points it is seen that the two patterns are reversed.

In the first photograph there are also to be seen many short black lines or vertical streaks of deposit running at right angles to main domain walls. They arise from accidental small depressions or troughs formed during polishing. When a trough runs perpendicular to the direction of magnetization of a domain, a stray field bridges the trough

and colloid particles are attracted into it. When, however, a trough runs parallel to the direction of magnetization, a stray field does not traverse it and colloid is not deposited. By deliberately making very fine scratches on the surface with a glass fibre [5], tests can thus be made of the direction of domain magnetization. On the basal plane of the cobalt crystal, characteristic star patterns are formed, as shown in figure 6.

EXPERIMENTS WITH SILICON-IRON CRYSTALS

Most domain studies have been made with crystals of silicon-iron containing some 3 per cent silicon. In these body-centred cubic crystals there are six directions of easy magnetization, parallel to the cube edges. The patterns which may be observed on a cube face, or (100) surface, are particularly instructive. In the demagnetized state the surface is usually covered by a 'fir-tree' pattern, like that reproduced in figure 7; its formation is explained as follows [5]. The branches of the fir-trees are formed when the crystal surface departs slightly from a true (100) plane. The trunk of the fir-tree in figure 7 is formed by the intersection of a 180° wall with the surface. The branches, which are magnetized in directions perpendicular to those of the main domains, are formed by ellipsoidally shaped closure domains which run out from the domain walls within the crystal to give triangular intersections with the surface. The function of the closure domains is to reduce 'free' surface magnetism as much as possible. The more accurately the surface approximates to a true (100) plane the larger and fainter are the branches.

In figure 8, obtained when a weak magnetic field was applied parallel to the 180° domain wall which runs near the middle of the picture, the directions of magnetization in certain domains are marked with arrows. In the case of the fir-tree with its branches perpendicular to the trunk shown in the upper left quadrant of the picture, the trunk is formed by the intersection of a 90° domain wall with the surface; i.e. the wall separates two domains whose magnetic vectors are perpendicular to each other. As before, the branches are formed by the intersection of ellipsoidal closure domains with the surface, and in this instance the branches join the trunk in two different ways.

Below the centre of figure 8 there appears a structure like a tree with a wide trunk. This is a structure which is termed a domain of reverse magnetization. As the weak magnetic field is

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increased, the wide trunk expands and the tree lengthens at an enormous rate, so that finally the whole surface is covered by the trunk and is one single domain.

QUANTITATIVE EXPERIMENTS

Interesting quantitative experiments have been made with specially cut and shaped crystals of silicon-iron. For example, H. J. Williams and W. Shockley [6] cut a section parallel to a cube face and then shaped it to form a kind of picture frame with its sides parallel to cube edges. In the unmagnetized state a single 180° domain wall was made to run in an unbroken manner completely round the surface of the frame, so that on the inner side of the wall the specimen was magnetized in a clockwise direction and on the outer side of the wall in an anticlockwise direction. By passing a current through a fine coil wound on one side of the frame the crystal could be exposed to a magnetizing field, whereupon the wall moved, and the changes in magnetization could be measured and correlated with the position of the boundary.

L. Néel [7] first drew attention to the remarkable behaviour of a thin specimen of iron cut as depicted in figure 1. The upper and lower surfaces are (100) planes and the sides are (110) planes, so that the long axis of the specimen is a $[110]$ direction, i.e. a diagonal drawn on a cube face. When only a very small field acts parallel to this axis the state of affairs shown in figure 1(a) obtains; successive principal domains are alternately magnetized parallel to the $[001]$ and $[00\bar{1}]$ directions, the two directions of easy magnetization. A simple system of q closure domains serves to prevent 'free' surface magnetism on the sides. When an appreciable magnetic field H is applied, the principal domain vectors rotate inwards as in figure 1(b), and simultaneously a new set of p closure domains is established.

Specimens cut according to figure 1 have frequently been examined [5, 8-10], and a pattern is shown in figure 9. A dense colloid solution was here used to bring out the direction of magnetization in alternate domains; the strange circular patterns in the middle of the picture are probably due to defects below the surface. In such experiments the magnetic field obtained by placing the strip between the poles of a simple electromagnet is measured by a magnetic potentiometer [11], and the period d is measured from photographic records. In figure 2 a series of measured values of d are plotted against the corresponding values

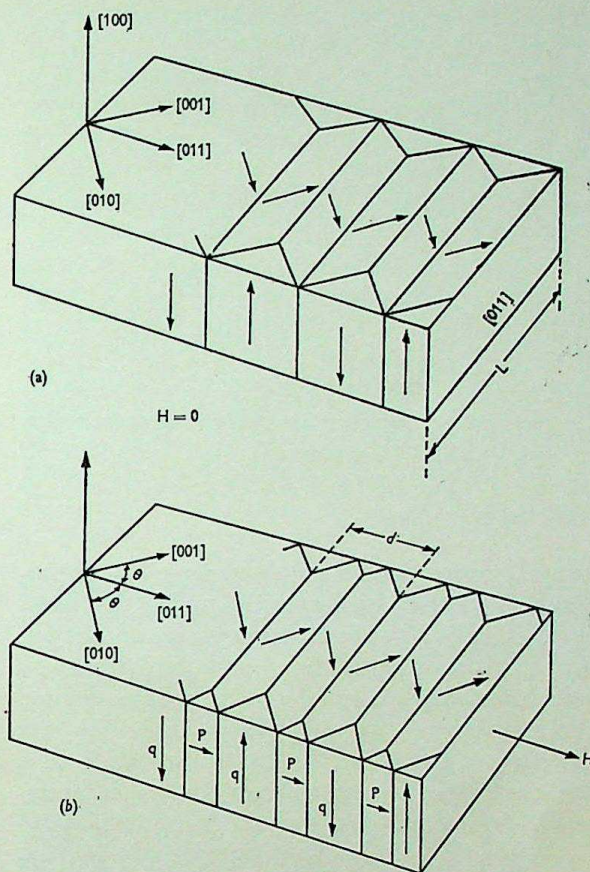


FIGURE 1 - Domain structure of Néel-cut specimen.

of the field H , together with the theoretical curve based on figure 1(b) [11]. There is undoubtedly numerical discrepancy between experiment and theory, but the general agreement is satisfactory. In any case exact agreement is not to be expected, because the patterns found on the (110) side surfaces, called lace patterns, are very complex. When the crystal is thick they are well defined, as in figure 12(a), with a period d' equal to that found on the (100) surface, although in some specimens [10, 12] they are inclined at an angle of as much as 15° to the expected direction; for this there is as yet no explanation. With narrow specimens, patterns like those of figure 12(b) are obtained. We have, in fact, definite evidence of 'free' surface magnetism, which is not envisaged in the theory.

THE EFFECTS OF IMPERFECTIONS

Néel was the first to point out that if there existed within a domain a defect, e.g. a tiny hole, an inclusion, or a small patch of strained material, a very large magnetostatic energy would be associated with it unless small closure domains were

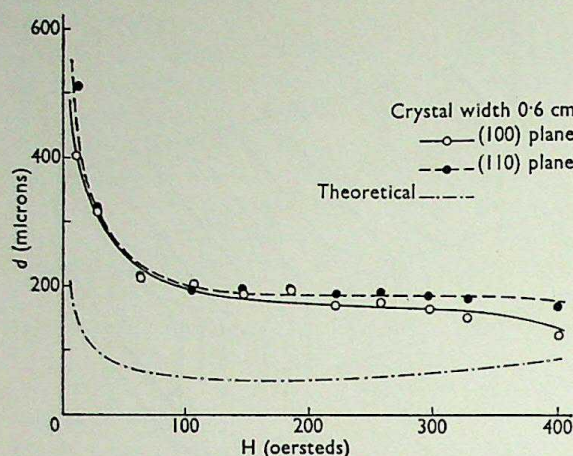


FIGURE 2 - Variation with field of domain spacings on (100) and (110) planes.

formed around it. Such systems were first photographed by the powder technique by Williams [13]. In figure 10 two closure systems are shown, one on either side of the 180° boundary which runs down the middle of the picture. Incidentally, this boundary is slightly waved, indicating the presence of many small defects, to which it is anchored. The closure systems are shaped somewhat like boomerangs, and they must be due to ellipsoidal-shaped structures, magnetized perpendicular to the main domain, giving triangular intersections with the surface.

Remarkable sequences of pictures were obtained by D. H. Martin [14] when 90° and 180° boundaries were caused to move across inclusions by the application of a magnetic field. But before similar pictures are described here it is helpful to discuss a phenomenon whose importance has only recently been appreciated [6, 15]. In figure 11 two 180° walls are seen. To the left of the wall nearest the middle of the picture is an inclusion on which is based a long Néel 'spike' closure domain, pointing upwards to the left. Between the two 180° walls is a somewhat deformed spike arising from another inclusion. But, in addition to the spikes, one notes that both inclusions are anchored to the 180° walls by tubes. It is now thought that such tubes play an important part in hysteresis phenomena. As a wall moves away from an inclusion, the tube reaches a critical length and then collapses to form a spike. In like manner, when a wall approaches a short spike, the latter elongates and attaches itself to the wall. This phenomenon is described as tube extension (*Schlauchziehen*); it is now being studied under controlled conditions.

During such a study P. M. Griffiths obtained the set of pictures shown in figures 13(a-f). In this can be followed the approach of a 180° wall towards a small pit formed in the surface during polishing, its sweep through the pit, and its eventual movement away from it. As the wall moves from right to left, we note the collapse of the tubes anchored to the wall, their almost complete disappearance when the wall intersects the pit, and their re-formation as the wall moves away from it. Finally, we see that one of the tubes, the upper in (f) has collapsed to form a spike. Figure 13(c) gives an excellent idea of a highly localized closure domain system formed when the plane of the wall intersects the inclusion. Such processes cannot be reversible, yet they must be common inside polycrystalline materials, and their formation and disappearance must be accompanied by micro-eddy current thermal changes [16].

It is pertinent to enquire what happens when a specimen is magnetized more or less to saturation in a strong field, so that it is effectively one large single domain, and the field is then slowly reduced to zero. Why should the single domain configuration not remain? Taking the simplest case, that of a (100) surface of silicon-iron magnetized to saturation along a cube edge, Martin [16] showed the extraordinary importance of inclusions, imperfections, and artificial defects. He showed that from such centres there arise domains of reverse magnetization, such as the one mentioned in describing figure 8. Once formed, these domains need only a small change of field to cause them to sweep across the whole surface.

NEW PATTERNS OF SPECIAL SIGNIFICANCE

In order to find to what extent the patterns found on polycrystalline surfaces resemble those on single crystal surfaces, A. Hart [17] made a special study of grain-orientated silicon-iron in which the planes of intersection of many of the grains in a sheet surface are close to a (110) plane. Patterns were observed which were virtually the lace patterns previously observed on the (110) surface of a Néel-cut specimen. In the course of this study some interesting 'tadpole' patterns were recorded. They always appeared near the edge of a grain, and it was therefore concluded that they were a special type of closure structure covering a more elementary domain structure, and that the heads of the tadpoles were evidence of highly localized stray fields. It is now considered that they are formed by the intersection of a large Néel

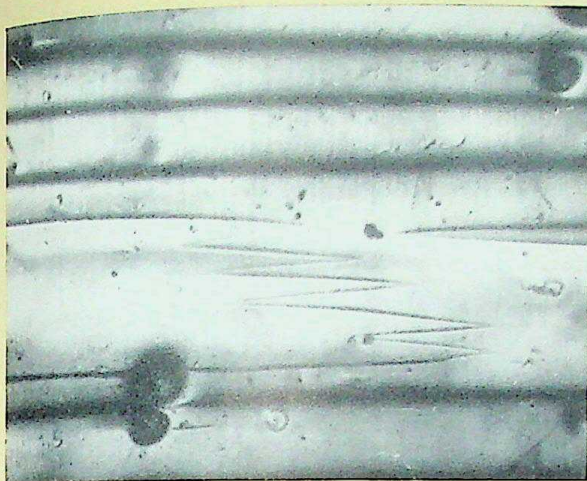


FIGURE 3 - Powder patterns on the $(10\bar{1}0)$ face of a single crystal of cobalt in the demagnetized state. ($\times 110$)

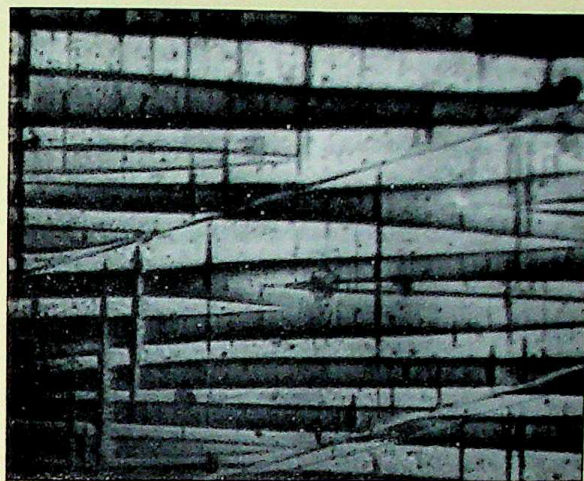


FIGURE 4 - Cobalt. Demagnetized state, $(10\bar{1}0)$ surface. Small normal field applied. ($\times 125$)

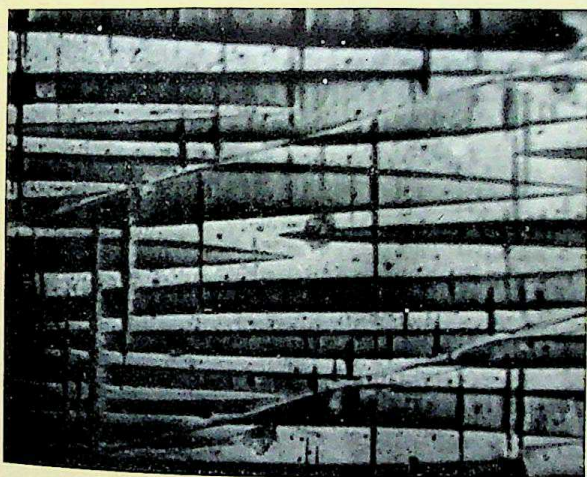


FIGURE 5 - Cobalt. Demagnetized state, $(10\bar{1}0)$ surface. Same as figure 4 but with field reversed. ($\times 125$)

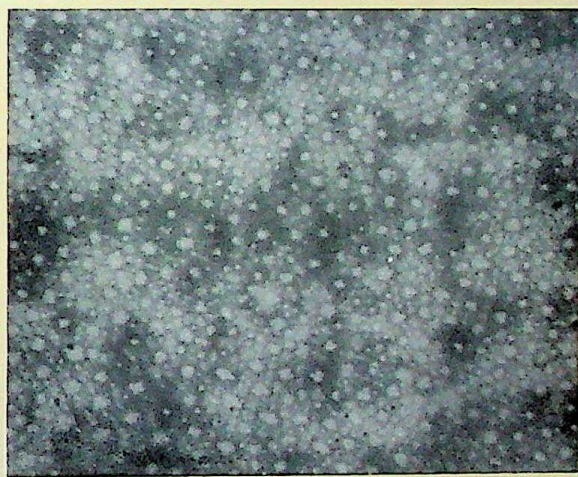


FIGURE 6 - Powder pattern on the basal plane of a cobalt crystal in the demagnetized state. ($\times 110$)

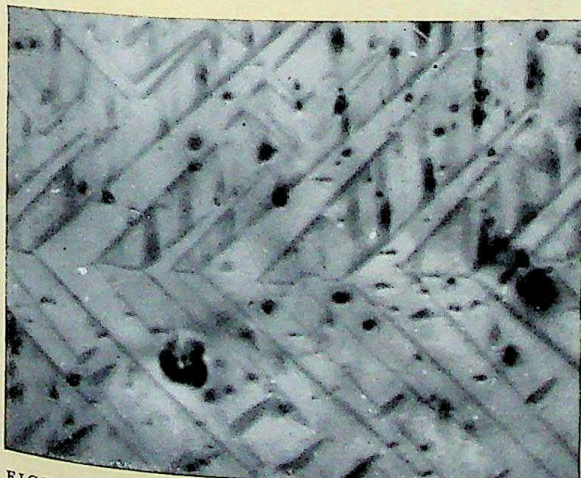


FIGURE 7 - 'Fir-tree' patterns on approximate (100) surface of silicon-iron in the demagnetized state. ($\times 180$)

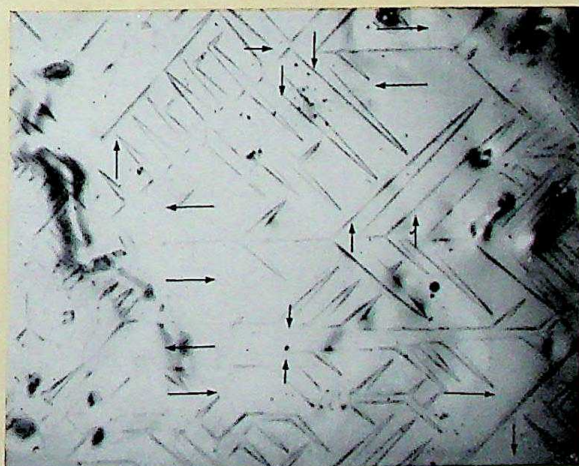


FIGURE 8 - 'Fir-trees' and a domain of reverse magnetization on approximate (100) surface of silicon-iron; a very weak field acts on the almost demagnetized crystal. ($\times 80$)



FIGURE 9 - Lines on Néel-cut silicon-iron crystal. Field applied parallel to $[011]$ direction, i.e. perpendicular to the lines of colloid. ($\times 125$)

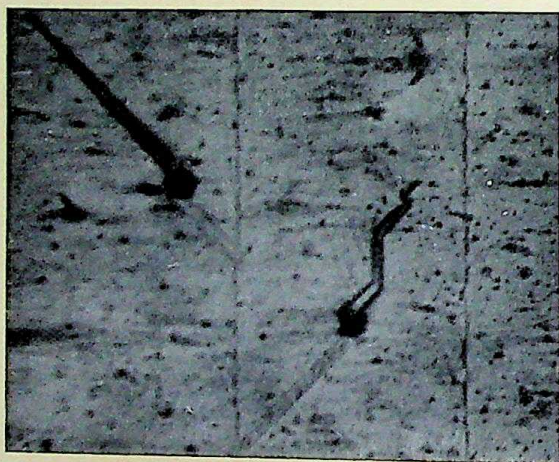


FIGURE 11 - Néel spikes, and tubes attached to an inclusion and a 180° wall, on a (100) surface of silicon-iron. ($\times 90$)

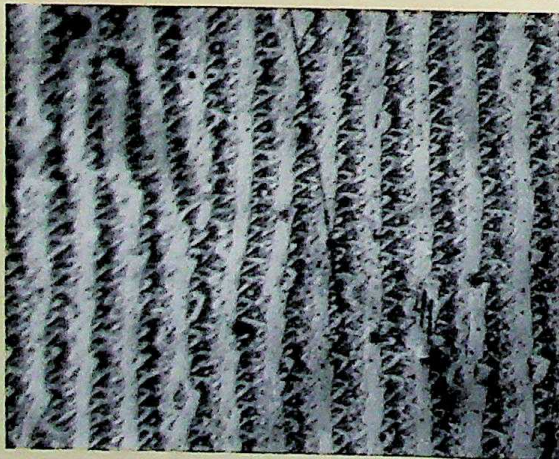


FIGURE 12(a) - Lace patterns on (110) surface of silicon-iron. ($\times 115$)

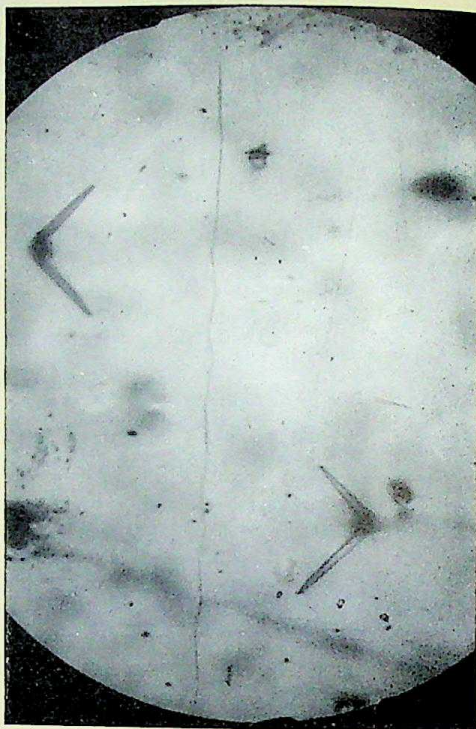


FIGURE 10 - Closure domain structures on a (100) surface of silicon-iron. A 180° boundary runs through the middle of the picture from top to bottom. ($\times 200$)

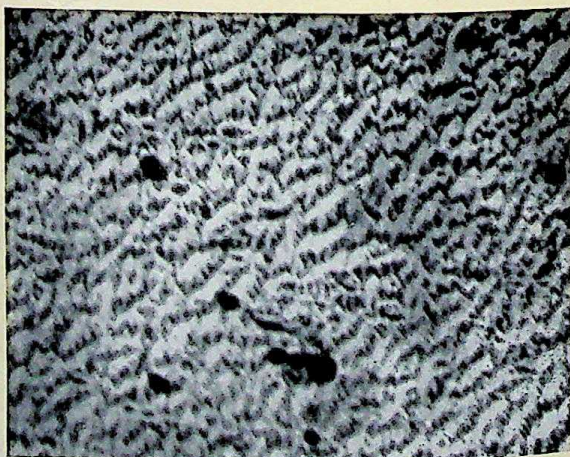
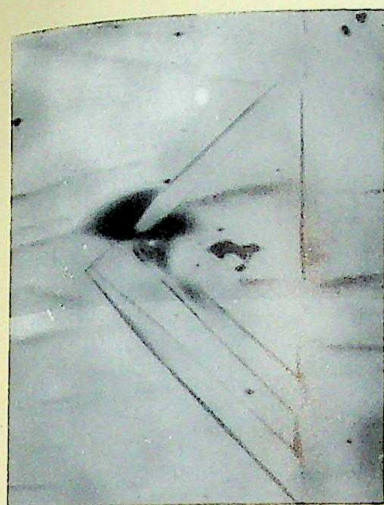
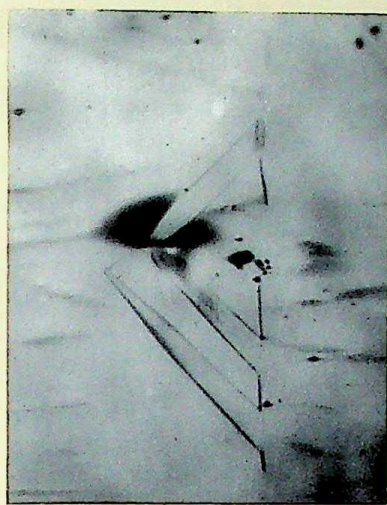


FIGURE 12(b) - Lace patterns on (110) surface of thin specimen of silicon-iron. ($\times 125$)



(a)



(b)



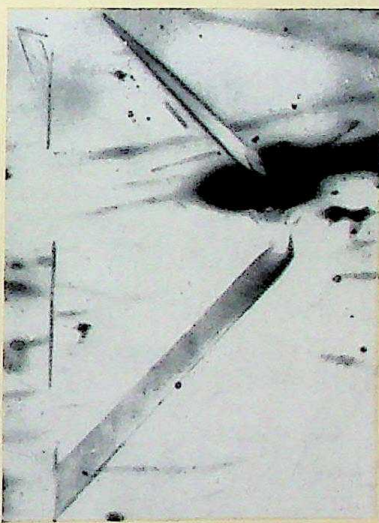
(c)



(d)



(e)



(f)

FIGURE 13 - Patterns on silicon-iron illustrating passage of a 180° wall across a small pit in the crystal surface; sequence from (a) to (f). Wall moves from right to left. ($\times 250$). (Note tree patterns around hole in (c).)



FIGURE 14(a) - 'Tadpole' patterns on polycrystalline silicon-iron grain with approximate (110) surface. A grain boundary is off the picture to the right. ($\times 100$)



FIGURE 14(b) - 'Tadpoles' and 'lozenges' on an approximate (110) plane of silicon-iron with a small field applied along a [110] direction. ($\times c. 100$)



FIGURE 15 - Echelon structure observed on a (100) surface of a rectangular block crystal of silicon-iron. Edge of block is at left edge of the photograph. ($\times 90$)

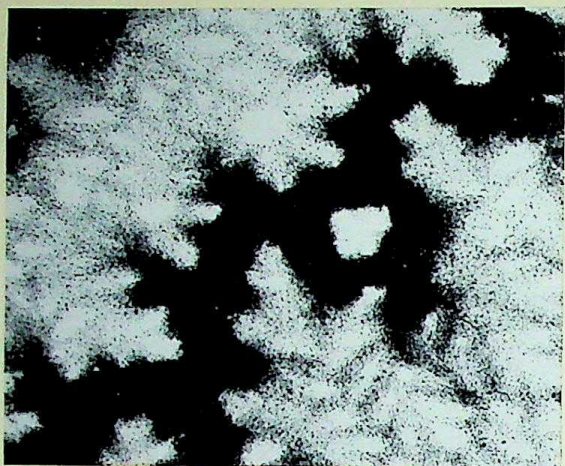


FIGURE 16 - Detail of pattern on basal plane of cobalt. ($\times 7800$)



FIGURE 17 - Tip of dagger closure domain on cobalt. Scratch in upper portion of picture. ($\times 5900$)

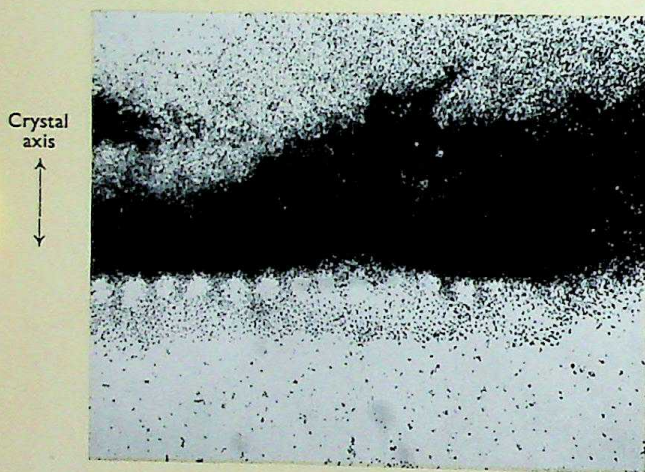


FIGURE 18 - Scratch on cobalt surface. ($\times 5000$)

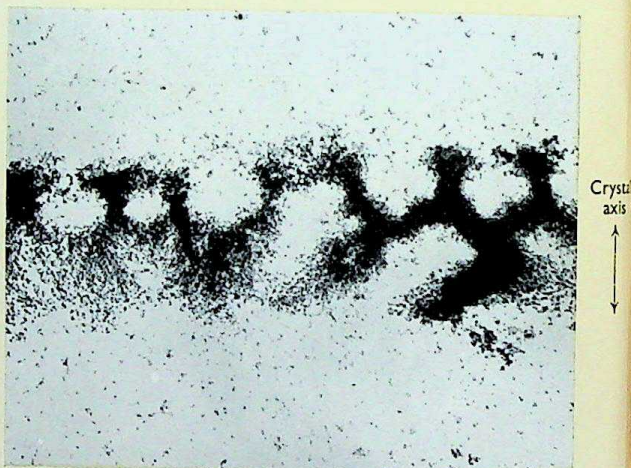


FIGURE 19 - Strain pattern on cobalt crystal surface. ($\times 5900$)

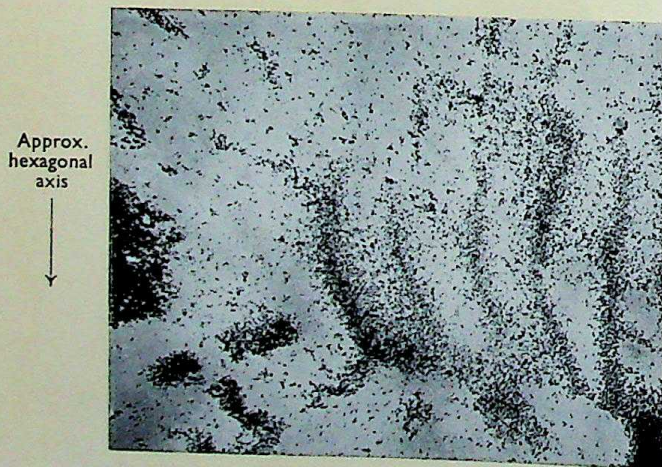


FIGURE 20 - Powder pattern on a grain of barium ferrite (Magnadur). ($\times 5000$)



FIGURE 21 - Pattern on the basal plane of a plate-shaped grain of barium ferrite. ($\times 5900$)

'spike' closure domain with the surface, and a satisfactory model of their formation can be given.

Further information about these structures was obtained by P. F. Davis [18] using large-grained specimens of silicon-iron whose surfaces were approximately (110) planes. W. S. Paxton and T. G. Nilan [19] had found lozenge-shaped patterns when a thin surface was inclined at an angle of between 4° and 7° to a true (110) plane, the specimen being either in a demagnetized or a weakly magnetized state. In figure 14(a) many tadpoles, and in figure 14(b) many lozenges, are to be seen. It is thought that lozenges are formed by the intersection with the surface of domains of reverse magnetization situated in the principal domains, which in thin specimens are arranged in layers, almost parallel to the surface, alternately magnetized in opposite directions (i.e. parallel to the [001] and [00 $\bar{1}$] directions). The lozenges are therefore perpendicular to the [110] direction; individual tadpoles set parallel to the [111] direction. At an international conference held in Moscow [23] in 1956, Shur showed records of lozenge patterns obtained on sheets of silicon-iron some 6 to 50 μ in thickness; he emphasized that, even when the material is saturated, the lozenges do not completely disappear. This would mean that nuclei for domains of reverse magnetization are always available.

Martin found that when a rectangular block specimen of silicon-iron, with every face a (100) plane, is cut so that one end of the block terminates in a (111) surface, a very complicated 'echelon' pattern, with an extremely fine texture, was found on the (100) surface in the demagnetized state. A model indicating how such a pattern may be formed is shown in figure 22, and an excellent photograph of such a pattern is given in figure 15. Martin [20] has used the model in a calculation of the optimum domain size and its dependence on crystal size. He found that for a block specimen of rectangular cross-section with (111) planes at both ends it is nearly the same as that for a similar specimen with (010) faces at both ends, and that even if 180° boundaries are replaced by 90° boundaries the change in energy involved is very small. This remarkable result must influence our views of magnetization processes.

ELECTRON MICROSCOPE STUDIES

A new technique which appears to have great possibilities has recently been devised by D. J. Craik [21], who is able to prepare a kind of thin film replica of a domain pattern and to remove

it from the metal surface for examination with either a light or electron microscope. For this purpose colloidal magnetite is prepared according to the Elmore recipe and peptized sufficiently for it to pass through fine filter paper. To the filtered solution 0.1 per cent of a commercial methyl ether of cellulose ('Celacol') is added, and any free acid is removed by repeated dialysis with distilled water. A drop of the treated solution dries to form an amorphous film a few hundred Ångströms thick.

Upon the metal surface to be examined is placed a thin film of Formvar resin some 200 Å thick; if necessary, the metal surface can be protected from rusting, etc., by first depositing on it a fine layer of quartz by evaporation *in vacuo*.

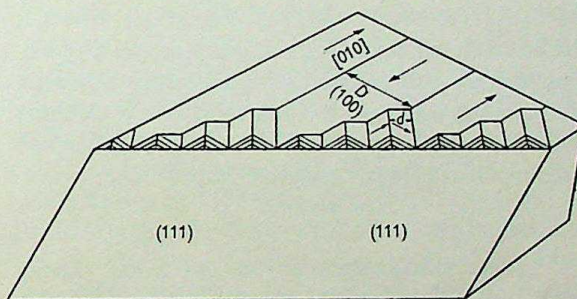


FIGURE 22 - Model to illustrate 'echelon' pattern formation on (100) plane of silicon-iron.

Sufficient colloid is placed upon the resin film to form a layer about 500 Å thick. The Bitter pattern is formed, and the colloid is allowed to dry *in situ*. The film is removed by placing a few drops of a thick solution of collodion in amyl acetate upon it; when this has dried, the whole may be detached freely. The record so obtained is permanent. Chosen portions of the record are now placed, with the collodion surface downwards, on the standard copper grids used in electron microscopy. These are placed on strips of stainless steel mesh, below which amyl acetate may be introduced to dissolve away the collodion.

Photographs illustrating the excellence of this new technique are shown in figures 16-20. Figure 16, which may be compared with figure 6, shows some of the fine detail in the powder pattern obtained on the basal plane of a cobalt crystal in the demagnetized state. Figure 17 is a record of the tip of a dagger-shaped closure domain, or domain of reverse magnetization, running horizontally, together with a scratch in the upper portion of the picture. A better example of a photograph of a scratch is seen in figure 18. The lower

border of the scratch is edged with fine hexagonal deposits characteristic of strained cobalt; another strain pattern is reproduced in figure 19.

It is important to apply this new technique to the examination of materials whose domain features are less well known than those of cobalt. A start has been made, and in figure 20 we have a typical domain pattern recorded on a large grain of barium ferrite (Magnadur). The particle is about $5\ \mu$ thick; a grain boundary lies to the right and the hexagonal axis of the crystal runs approximately vertical in the plane of the photograph. The domain walls are about $1\ \mu$ apart.

When particles are so small that domain boundaries cannot exist within them, it follows that their magnetization can be reversed only by a difficult rotation process, and this means a very high value of the coercivity. Figure 21 shows a record of the pattern on the basal plane of a plate-shaped grain of barium ferrite about $5\ \mu$ across, taken in the course of a study on domain patterns on grains which approach the critical size below which domain boundaries are impossible.

CONCLUSION

The foregoing account suffers from certain omissions due to lack of space. For example, no mention is made of patterns on nickel, whose study is difficult because the face-centred crystal possesses

eight directions of easy magnetization, the [111] directions, and because its properties are so profoundly influenced by strain. Yet very beautiful pictures have been obtained by Japanese workers [22]. No mention is made of the maze patterns which are found on surfaces from which the Beilby layer has been only partially removed by electrolytic means, and whose study has recently provided additional information about closure domains [23]. Some beautiful and fundamental experiments on polycrystalline sheets of Perminvar [24] are not described, although these have shown how a single domain wall may be caused to form a closed path within a surface on a ring of the material. Experiments on permanent magnet materials [12] have also been omitted. But it is hoped that enough has been written to prove that the Bitter figure technique has enabled us to establish the correctness of the domain concept and to obtain much new information concerning important magnetic processes of which we were previously ignorant.

ACKNOWLEDGMENTS

The author would like to thank all those who have collaborated with him in these researches and in producing the pictures used in this article. The photograph of figure 14(b) was taken by Dr A. Hart, those of figures 16-21 by Mr D. J. Craik, and the remainder by Mr P. F. Davis and Mr P. M. Griffiths.

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Gibberellic acid

P. W. BRIAN and JOHN FREDERICK GROVE

Although it has been known for some thirty years that a metabolic product of the fungus *Gibberella fujikuroi* has a striking effect on plant growth, it is only comparatively recently that it has received detailed investigation. Research has now established the main chemical features of the biologically active substance and has elucidated its effects on the growth of plants. While the properties of gibberellic acid have naturally evoked much speculation about its practical applications in agriculture, no major applications have yet been found.

INTRODUCTION

In all countries where rice is grown, a soil-borne disease of rice caused by the fungus *Gibberella fujikuroi* (conidial state: *Fusarium moniliforme*) has been recorded. In most respects the symptoms of the disease are not unlike those of many other *Fusarium* diseases; the fungus enters through the roots and stem-base, causing local necrosis, and as it spreads in the host tissues the vascular system of the shoot turns brown and the shoot wilts. Many infected seedlings eventually die. But one early symptom is unique: the stems and leaves of some infected seedlings elongate more rapidly than those of healthy plants, so that an infected field looks as though it had been sown with a mixture of tall and short varieties of rice. This disease has been much studied in Japan and Formosa, where it is known as the bakanae disease.

Thirty years ago the Japanese plant pathologist E. Kurosawa [1] made the important discovery that cell-free filtrates made from pure cultures of *G. fujikuroi* grown on synthetic media would, if applied to healthy rice seedlings, produce the elongation symptoms characteristic of the disease. It therefore seemed almost certain that a metabolic product of the fungus, produced when it grew in either the host plant or in culture media, was responsible for the enhanced growth.

This observation was rapidly followed up in Japan, and it was soon shown that many other species of plant responded by extra growth. The effects observed were confined to shoot growth: root growth was either unaffected or slightly depressed. The conditions of production of the active material were studied, using the response of rice seedlings as a crude form of bioassay. Work on extraction and purification of the active material proceeded at the same time, and it was found that it could be adsorbed on charcoal and eluted with certain organic solvents. Eventually, in 1939, a crystalline material was obtained, in yields of

about 10 mg per litre of crude culture media, which would stimulate growth if applied to the roots of seedlings in concentrations of a few parts per million; this was named gibberellin A [2]. Further work on the chemistry of gibberellin A and on its physiological properties was published in Japan, but because of the war it did not become known in Europe or America until several years after publication.

More recently, interest in the growth-promoting metabolites of *Gibberella fujikuroi* has spread, and from this increased attention has resulted the discovery of three related active compounds, each of similar physiological activity: these are now known as gibberellin A₁, gibberellin A₂, and gibberellic acid [3]. The last-named component, gibberellic acid, was first obtained in pure form independently, and almost simultaneously, in Britain and the United States. Gibberellic acid can now be produced in much greater yields than either gibberellin A₁ or A₂, and more detailed and fruitful work on its chemistry, physiological activity, and possible practical uses has been carried out than was possible with the original gibberellin A. The present article deals mainly with this more recent work.

PRODUCTION OF GIBBERELLINS AND GIBBERELIC ACID

The earlier Japanese production method was based on surface culture of *Gibberella fujikuroi* on liquid media. Precise compositions of the media used were not published, but they appear to have been simple glucose/salts or glycerol/salts media, with ammonium chloride as the source of nitrogen. The cultures were incubated for 30–45 days at 25° C. The active material was isolated from filtrates of such cultures by a rather complex procedure. The basic step in the isolation was adsorption of the active material on carbon, from which it was eluted with methanolic ammonia. A

purification procedure consisting of several stages followed. Yields of about 10 mg per litre of 'crude gibberellin crystals' were obtained [4].

The development of stirred and aerated deep fermentation techniques for antibiotic production suggested that these methods might be used for gibberellic acid production. Japanese workers, using a single-stage fermentation and the same culture medium as they had used for surface culture, obtained yields not exceeding 8 mg per litre in a fermentation lasting 96 hours at 27° C. Using a three-stage fermentation with a 1.5–2.0 per cent glucose/salts medium, an American group obtained yields of 17 mg per litre of mixed gibberellin A and gibberellin X (= gibberellic acid) in a fermentation at 25° C whose total duration was 95 hours. Their media and extraction methods were essentially similar to those used by Japanese workers [3, 5].

Much greater yields of gibberellic acid, approaching 200 mg per litre, have been described by a British group [6] using a single-stage stirred fermentation. Though they used a different strain of the fungus, it is most probable that changed fermentation conditions were mainly responsible for the increased yield. These changes involved (a) use of a medium with higher sugar content (4 per cent glucose or sucrose), and (b) use of much longer fermentation times, maximum yields being obtained in 18 days at 25° C. These workers found that although glycerol media supported good growth, they were inferior to sucrose or glucose as sources of carbon for the production of gibberellic acid. Their method of extraction was somewhat simpler than the Japanese method, though it was basically similar; the gibberellic acid was removed from culture filtrates by adsorption on carbon, from which it was eluted with aqueous acetone.

EFFECTS OF GIBBERELIC ACID ON EXTENSION GROWTH OF PLANTS

Shoot growth. The mode of application of gibberellic acid is not critical. Essentially similar responses are elicited if it is sprayed on the shoot as a whole, if applied to any single leaf in a microdrop of water or alcohol, or if the roots are treated by including gibberellic acid in the soil or culture solution. The microdrop application to leaves is convenient in quantitative work.

The types of growth response are best described by reference to a few examples. Wheat seedlings are increased in height (figure 2). This is due to increase in length of both stem internodes and leaves. The leaves may be as much as 50 per cent

longer than those of untreated plants, but are somewhat narrower and usually paler in colour. This chlorosis is most marked in plants growing in soils or culture solutions of low nutrient value. If no mineral nutrients are limited, the reduced depth of colour is transient. Such quantitative data as have been published [7] refer to the application of gibberellic acid to roots; in such experiments an effect can be detected when gibberellic acid is present in the nutrient to the extent of 0.1 µg per ml, and maximal effects are produced by 1–10 µg per ml. In experiments in which wheat plants were sprayed weekly with gibberellic acid (100 µg per ml) until maturity, the mean height of the flowering stems was increased by 25 per cent. There were, however, rather fewer ears, this being associated with a 25 per cent reduction in the total number of tillers produced. The ears emerged from the sheathing leaves a few days before those on untreated plants.

The growth of dwarf varieties of garden pea (*Pisum sativum*) is greatly stimulated by gibberellic acid. Stem internode length may be increased by 200–400 per cent; leaf petioles are increased in length to much the same extent, but leaf size is not so much affected as in wheat and other cereals. Though treated plants are at first somewhat paler in colour than normal, this effect is less noticeable than in cereals. Quantitative data relating dose and response are available for the dwarf pea [8]. An obvious effect is produced by a dose of 0.01 µg per plant; above this level the response is linearly related to the logarithm of the dose in the range 0.01–0.1 µg (figure 1). The response to a single dose is temporary. Immediately after application, growth is accelerated: the size of the dose applied does not greatly influence the newly established growth rate, but does influence the time over which this accelerated growth is maintained. Eventually, growth rate slowly subsides to that of untreated plants (figure 3). To maintain an increased growth rate over the whole life cycle of a plant, gibberellic acid must be applied at fairly short intervals. In an experiment in which dwarf pea plants received weekly doses of 1 µg gibberellic acid, the final height was increased by 50 per cent, but the total number of stem internodes was unchanged [9]. Thus the effect of gibberellic acid on the pea plant is to increase height solely by increasing internode length. Moreover, this increase in internode length is almost entirely due to increased cell extension; there is little evidence of increased cell multiplication.

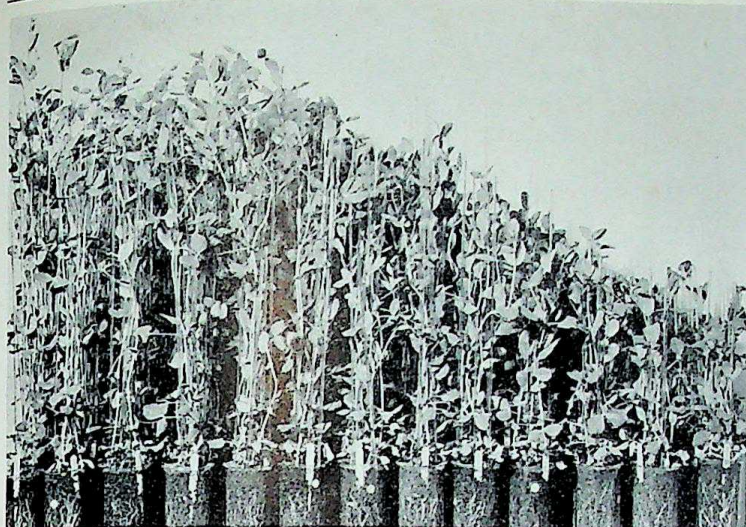


FIGURE 1 - 'Meteor' pea seedlings 26 days after application of gibberellic acid (GA). Reading from right to left: Nos. 1 and 2 were untreated; No. 3 received $0.01 \mu\text{g}$ GA. Thereafter doses increased in twofold steps up to No. 13, on the extreme left, which received $10.24 \mu\text{g}$ GA [8].



FIGURE 2 - (Right) Wheat seedlings grown in Pfeffer's culture solution (left), and (right) in a similar solution containing $2 \mu\text{g}$ per ml gibberellic acid.

The effects of gibberellic acid on the 'Cupid' sweet pea (*Lathyrus odoratus*) (figure 4) differ in several respects from those just described for the garden pea. The 'Cupid' sweet pea is a very dwarf type, with a bushy habit and leaves much smaller and darker in colour than those of the more usual climbing sweet pea. Early in growth, when the main axis is about six inches high, further development of the main axis normally ceases, and some

lateral buds develop into branches which may become as long as the main axis, thus giving rise to the bushy habit. Application of a weekly dose of $1 \mu\text{g}$ gibberellic acid completely alters the plant habit. In an experiment in which seedlings 3 cm high were treated in this way, growth of the main axis was much accelerated: after three weeks, untreated plants were 7 cm high and treated plants 42 cm high. At this point lateral branches developed rapidly on the untreated plants, but much less rapidly on the treated plants. The general growth picture after 7 weeks' growth is shown in table 1. Whereas untreated plants had developed six side branches, each roughly of equal length and having the same number of internodes as the main axis, growth in the treated plants proceeded predominantly in the main axis, which was about ten times taller than that of the untreated plants. The total number of internodes formed was not altered. The leaflets were altered in colour and shape, becoming pale green and lanceolate, as is usual in climbing sweet peas, instead of dark green and ovate. Moreover, the surface area of each leaflet was approximately doubled. An effect of this kind on leaf area is unusual in dicotyledons. This change in growth habit, from dwarf bushy plants to tall climbing ones, has also been noticed in dwarf beans [7, 10].

Such increases in shoot height are often accompanied by increases in the fresh and the dry weight

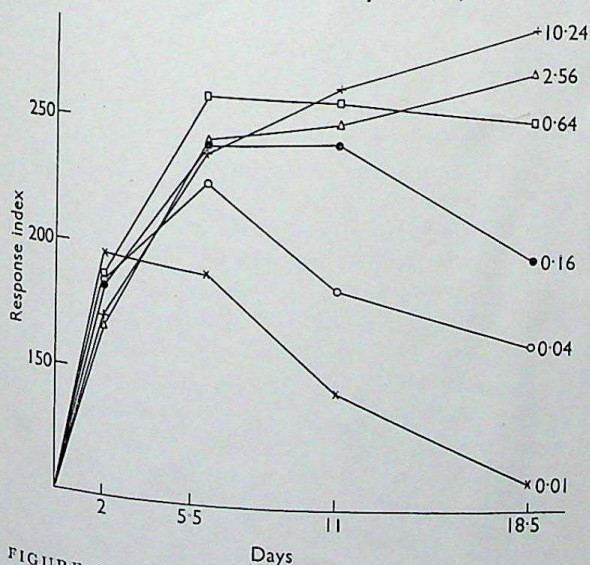
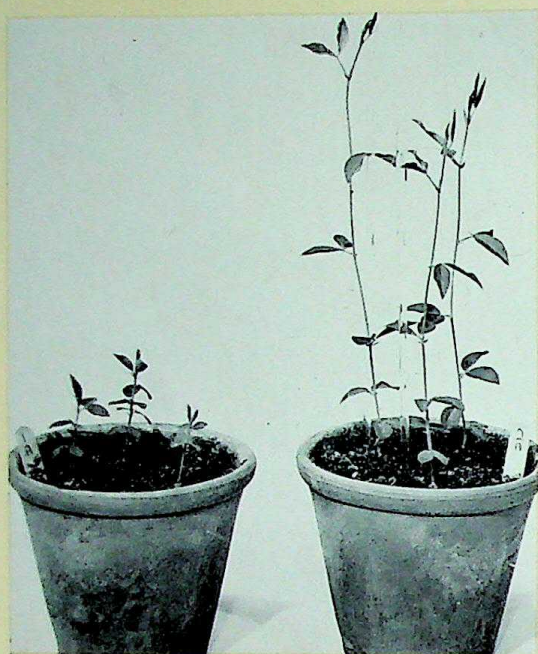
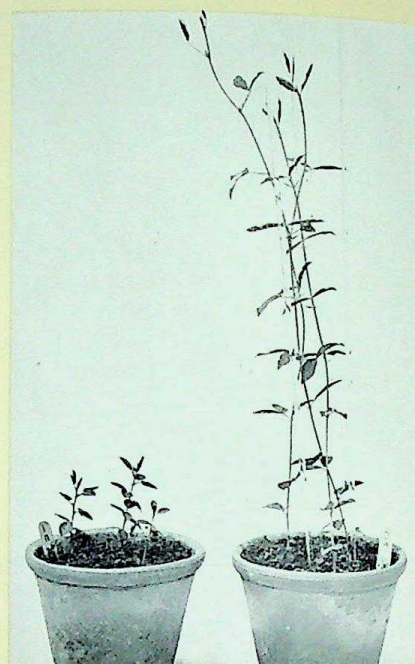


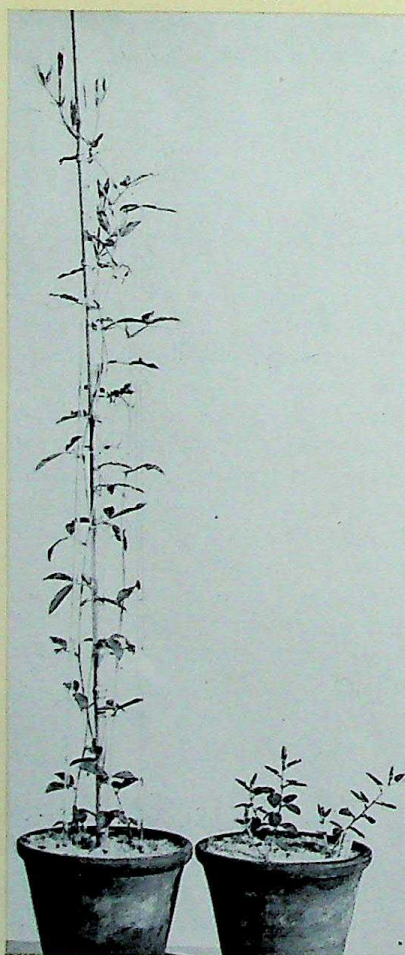
FIGURE 3 - Growth rates of 'Meteor' peas treated with gibberellic acid, expressed as percentage of that of untreated plants. Doses of gibberellic acid (μg) are indicated on the right [8].



(a)



(b)

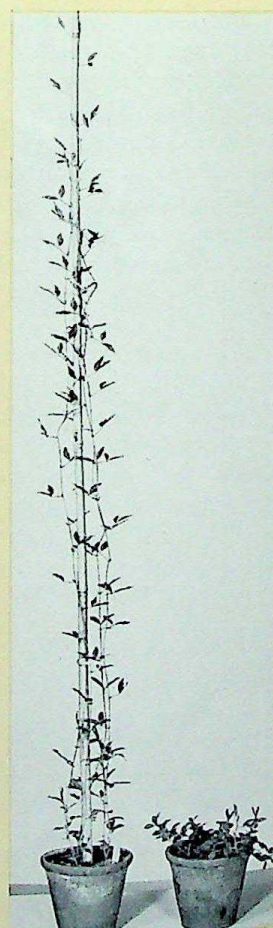


(c)

FIGURE 4—Effect of doses of $1\mu\text{g}$ gibberellic acid weekly on growth of 'Cupid' sweet peas. (a) 2 weeks; (b) 3 weeks; (c) and (d) 4 weeks; (e) 7 weeks after first treatment. The effect on the shape of leaves is shown most clearly in (d). Plants treated with gibberellic acid are on the right in (a) and (b), and on the left in (c), (d), and (e).



(d)



(e)

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TABLE I

Mean effect of weekly doses of 1 μ g gibberellic acid on growth of 'Cupid' sweet peas. (Measurements made after 7 weeks' growth)

Treatment	Height (cm)	Number of internodes in main axis and all branches	Number of internodes in main axis	Number of branches
None ..	12	83	14	6
1 μ g weekly	122	82	43	4

of shoots. For example, increases of 24 per cent in dry weight of wheat seedlings and of 15 per cent in pea seedlings have been recorded in small-scale experiments with plants growing in culture solutions containing gibberellic acid. Increases of over 40 per cent in dry weight of grass yields in field plots have resulted from a single sprayed application of gibberellic acid. The cause of this increased yield has not been critically studied, but it seems probable that it is a secondary result of increased area of leaf and other photosynthetic surfaces. Increases in weight are marked only where initial nutrients are not so low as to limit growth. Even where the weight of plants as a whole is not increased, there may be a redistribution as between root and shoot so that shoot weight is increased and root weight decreased. This is particularly noticeable where there is nutrient deficiency [7, 10, 11].

A large number of species have recently been treated with gibberellic acid in simple observational experiments, and in most cases responses of the kind described above have been elicited; however, some plants do not respond at all, and in others such responses as have been seen are small [10, 12]. This variation in response is discussed further in a later section of this article.

Root growth. Root growth is not stimulated by gibberellic acid under any known circumstances. This is surprising and suggests that, contrary to what has usually been supposed, growth regulation in shoots and roots is in some respects essentially different. In relatively high concentrations gibberellic acid slightly inhibits root growth [8].

COMPARISON WITH AUXINS

The increased shoot growth induced by gibberellic acid is mainly attributable to cell extension.

Cell extension in plants is already known to be controlled by hormones called auxins [13], the best known of these being 3-indolylacetic acid. Many bioassays of auxins, notably the coleoptile-section straight-growth tests, are in fact based on the capacity of auxins to induce cell elongation. A detailed comparison of the physiological properties of gibberellic acid and indolylacetic acid reveals some interesting differences [9, 14, 15].

An important difference is to be seen in the effect of the two substances on extension of etiolated coleoptile sections. Indolylacetic acid very greatly increases the extension of such sections in the usual 24-hour observation period; the relation between amount of extension and the logarithm of the dose is approximately linear within the range 0.01–1.00 μ g/ml. Gibberellic acid, however, induces very little extension, and the dose-response curve flattens off very rapidly. Similarly, indolylacetic acid induces marked extension of internode sections in peas grown in the light, but gibberellic acid does not. We thus have the striking paradox that while gibberellic acid induces big extensions of growing tissues in intact wheat or pea plants, on which indolylacetic acid has little effect, with sections excised from growing zones of these plants the reverse is the case.

The auxins, in addition to their effect on cell extension, also affect cell division, stimulating cell proliferation in some tissues. For instance, treatment of cuttings with auxins accelerates root initiation. Gibberellic acid does not do this; indeed, it antagonizes the root-initiating effects of auxins.

If the main growing point of a plant is excised, one or more lateral buds commence to grow to take its place. If an auxin is applied to the decapitated top of the main shoot, development of the laterals is inhibited. Gibberellic acid has no such effect; indeed, it stimulates more rapid development of the laterals. But in those intact plants in which the main axis ceases to extend and laterals consequently develop, as in the case of the 'Cupid' sweet pea mentioned earlier, gibberellic acid applications enable the main axis to continue growth and formation of laterals is inhibited.

There are several other noteworthy differences. For instance, auxins inhibit leaf abscission; gibberellic acid does not. Excessive doses of auxin induce abnormal cell proliferation in some tissues; gibberellic acid does not.

All these striking differences between gibberellic acid and auxins lead naturally to the view that the two classes of substance must act differently.

Nevertheless, both induce cell extension under appropriate conditions, and it remains possible that in producing this effect they may act similarly. It has been shown [16] that extension of sections from growing internodes of peas is stimulated by auxins but not by gibberellic acid, but that in the presence of indolylacetic acid, gibberellic acid produces an extra amount of extension over and above that produced by optimal concentrations of the auxin. Thus gibberellic acid depends for its activity on the presence of indolylacetic acid. This probably explains why it produces a response in whole plants, with their auxin synthesizing system intact, but produces at most a slight response in auxin-depleted sections. The balance of evidence at present lies in favour of the view that the effect of gibberellic acid on growth is in some way distinct from that of the auxins, but that the two are complementary.

FURTHER PHYSIOLOGICAL EFFECTS OF GIBBERELIC ACID

We have so far described the effects of gibberellic acid on vegetative growth of plants whose requirements for normal growth and development are not critical. But many plants develop normally only if exposed, at suitable times during their life cycle, to certain quite specific stimuli. Not only vegetative growth may be so conditioned, but flowering may be even more affected. A preliminary study has been made of the effects of gibberellic acid on some plants of this kind, and the results are of particular interest.

There is a large class of plants which may be described as cold-requiring biennials. It includes several familiar crop plants, such as some members of the cabbage family, carrots, parsnips, and sugar-beet. In the first season of growth, in their natural habitats, such plants form a basal rosette of leaves, with negligible development of a stem axis. In the second year of growth, an elongated stem develops on which flowers are borne. Neither stem nor flowers are produced unless the plant is first exposed for a short period to a low temperature, the critical temperature varying from species to species. This stimulus is normally a consequence of winter conditions, but if applied artificially production of the stem axis will commence immediately, even in the first season of growth. Further growth of this axis, and production of flowers, is often also conditioned by the length of day. A. Lang [17] has described some effects of gibberellic acid on the growth and development of the common henbane (*Hyoscyamus niger*), a cold-requiring biennial which

also needs long days for complete development to the flowering stage. He found that fairly large doses, between 60 and 300 μg per plant, would induce formation of a stem in plants at the rosette stage if they were kept at temperatures well above that which normally induces such development, but that under the same conditions untreated plants all remained in the rosette stage. However, the effect of gibberellic acid was more marked in plants exposed to long daily lighting than in those exposed to short days; a dose of 60 μg had little effect on plants kept in short days, but markedly promoted stem extension of plants in long days. Larger doses promoted stem elongation even of plants grown in short days. Thus relatively small doses of gibberellic acid appear to replace the low-temperature stimulus completely, but much larger doses are required to replace the long-day requirements for normal stem extension. Differential effects on the growth of plants in long and short days have also been described for two annual plants [18]. The North American weed *Galinsoga parviflora* responds to gibberellic acid more in long days, but the corn-cockle (*Agrostemma Githago*) responds more in short days.

The *Hyoscyamus* plants treated with gibberellic acid in long days flowered normally; those grown in short days failed to flower, in spite of the production of a stem. Thus, of the conditions normally necessary for induction of flowering, gibberellic acid replaces the cold treatment but not the long days. This result is highly significant for two reasons. Firstly, it has been possible to achieve a clear distinction between the mechanisms of control of stem elongation and flowering. Secondly, this is the first case, with one exception, of chemical induction of flowering under strictly non-flowering environmental conditions. The one exception is the pineapple, which may be induced to flower by auxin treatment [13], but the flowering behaviour of the pineapple is in many respects anomalous.

Gibberellic acid also breaks dormancy of some seeds and tubers. For example, it induces sprouting of dormant potato tubers, and induces germination of dormant lettuce seeds which normally germinate only if exposed to red light [14, 19]. Auxins do not break dormancy, but gibberellic acid certainly is not unique in doing so; similar effects are sometimes produced by unsaturated hydrocarbons, ethylene chlorhydrin, and certain sulphur compounds such as thiourea or glutathione. It seems most improbable that the mechanism of action is the same for all these types of compound.

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Gibberellic acid thus appears to influence many physiological processes besides extension growth, but too little experimental work has yet been done for us to be sure whether some of these effects are general or are merely anomalous individual effects.

IS GIBBERELIC ACID A NATURAL PLANT HORMONE?

Stem extension, flowering, and breaking of dormancy of seeds and tubers are not obviously physiologically related processes, yet, in some plant species at least, gibberellic acid stimulates all these. It seems remarkable that a fungal metabolic product—produced, as far as is known at present, by a single species of fungus—should intervene in so many aspects of plant growth and development. It is remarkable, too, that none of its effects are abnormal, since most of them can also be induced by appropriate light and temperature conditions in the plant's environment. The physiological properties of gibberellic acid could be much more readily understood if it were structurally or physiologically related to some natural plant hormone or hormones: there is evidence that this may indeed be so.

First, there is genetical evidence. We have already mentioned the effect of gibberellic acid on the 'Cupid' sweet pea. This plant, which originally arose from a sweet pea of the normal climbing type by recessive mutation of a single gene, has smaller leaves, shorter internodes, and a more branched habit than the climbing type. Gibberellic acid treatment alters the growth form so that it approximates to that of the climbing sweet pea; it has no effect on climbing sweet peas themselves. Dwarf varieties of garden pea when treated with gibberellic acid assume the habit of tall peas [8], but tall peas are little affected by gibberellic acid. Here again, the dwarf plant is recessive to the tall, differing from it in a single gene. Some single-gene recessive dwarf mutants of maize assume the normal tall habit after treatment with gibberellic acid [20], but tall varieties are not affected. In each of these cases, and others could be cited, a recessive dwarf variety is induced by gibberellic acid to assume the growth habit of the tall variety from which it originally arose by mutation. Such instances are well known in microbial genetics. Thus, spores of the mould *Neurospora*—which will grow on a simple glucose/salts medium—if treated with X-rays will give rise to some mutant colonies which will no longer grow normally on the glucose/salts medium but need also aneurin (vitamin B₁). Such strains, called 'aneurinless', are recessive to

the wild type and differ from it in a single gene. Biochemically, they differ from the wild type in that, unlike the latter, they are not able to synthesize aneurin in sufficient quantity to maintain normal growth. By analogy, it is reasonable to explain the differential response to gibberellic acid of dwarf and tall varieties of plant by assuming that the dwarfs have lost the power to synthesize some substance, hormonal in nature, that can be replaced by gibberellic acid. It may be mentioned in passing that this is perhaps the first record of the effects of a mutation in a higher plant being reversed by supplying a specific chemical substance.

Secondly, there is more direct biochemical evidence. In 1951, before interest in the gibberellins had spread beyond Japan, J. W. Mitchell, D. P. Skaggs, and W. P. Anderson [21] showed that ether extracts of immature dwarf bean seeds contained substances which would stimulate elongation of the epicotyls of dwarf bean seedlings to a degree much exceeding that following auxin application. Following up this observation, it has been found that such seed extracts induce growth of dwarf mutant maize and dwarf peas precisely as gibberellic acid does. The active material moves in chromatograms in the same way as gibberellic acid [22]. Similar materials have been found in shoots of tall and dwarf pea seedlings [23]. It is not yet known whether there is more of this substance in tall than in dwarf pea shoots, but if this were found to be so, the interpretation of dwarfness as a failure to synthesize sufficient of a hormone resembling gibberellic acid would be greatly strengthened.

Let us assume for the moment that the existence of such a hormone in plants is established. We can then envisage growth and other aspects of development as being regulated by a balance of auxins and the hormone. We already know that growth, flowering, and dormancy phenomena are in some way bound up with auxin metabolism, but it has never been possible to explain them solely in such terms, just as dwarfness is inexplicable in terms of auxin alone [24]. It already seems possible that much more will be explicable in terms of an interacting system of the two kinds of growth hormone, possibly acting in association also with inhibitor systems. The work that will prove the worth of such speculations as this is still in progress, but it is interesting to reflect that these new possibilities have arisen largely as a result of the simple observations on bakanae disease of rice made by Kurosawa in 1926.

PROSPECTS OF APPLICATION

Naturally enough, the remarkable effects of gibberellic acid on plant growth and development have led to much speculation concerning its possible application in agriculture. This is a matter which can be settled only by field experiments; there is no *a priori* reason why it should be of practical use. Although indolylacetic acid has been found to play a most important role in controlling cell growth and cell multiplication in plants, it has found no use in agriculture, although structurally analogous substances, such as 2:4-dichlorophenoxyacetic acid, have found use as inhibitors of plant growth.

Possible applications of gibberellic acid can best be discussed in relation to the four types of physiological response described earlier in this article: (1) increase in dry weight of shoots, (2) increase in height of main-stem axis, (3) induction of flowering in biennials without need for a cold treatment (vernalization), and (4) breaking of dormancy.

Of these, the first is potentially of greatest importance. As we have seen, increases in fresh and dry weights of shoot tissues are sometimes obtained in small-scale laboratory experiments. The only detailed field work so far published is that of D. G. Morgan and G. C. Mees [11]. In their experiments, gibberellic acid in aqueous solution was sprayed on growing crops at a dose of 2 oz per acre.

With most crops the results were disappointing, in so far as increased growth of stems and leaves was not accompanied by increased crop yield. This was true of tomatoes, blackcurrants, peas, and beans. Wheat crops treated in spring responded by more rapid growth soon after treatment but yields of grain and straw at harvest were unaffected. Yields of root crops were reduced. Only with grass were consistent yield increases obtained.

In experiments on grass swards at several centres, the grass was cut four to ten weeks after application of gibberellic acid at 2 oz per acre. Growth of all the plants in the sward was obviously accelerated, even under conditions in which fertilizers produced no response. This was accompanied by quite considerable increases in dry matter (table II). The nitrogen content of the grass was slightly lower than that of untreated grass, so that crude protein yields were not increased to the same extent as total dry matter. At first sight these results seem very promising. However, if the grass was allowed to grow for a further period the yields from treated plots were lower than those from untreated plots (table II), so that the net effect of treatment was negligible. The reason for this depressed growth at the second cutting was not obvious. These trials show the need for caution in extrapolating the results of laboratory experiments to field conditions.

TABLE II

Differences in the dry weight yields of grassland at two cuttings, following treatment with gibberellic acid [11]

Date of treatment	Dry weight yields at cutting 1			Dry weight yields at cutting 2		
	Untreated control (cwt/acre)	Increase (cwt/acre) due to 2 oz/acre GA	Increase as percentage of control	Untreated control (cwt/acre)	Decrease (cwt/acre) due to initial GA treatment	Decrease as percentage of control
1st March 1955 ..	19.8	3.1	16	30.8	3.9	13
4th March 1955 ..	12.2	4.0	33	13.5	3.0	22
14th March 1955 ..	29.8	4.3	14	29.2	3.7	13
18th March 1955 ..	9.1	3.9	43	13.2	2.4	18
18th March 1955 ..	11.3	1.6*	14	16.7	2.0	12
13th April 1955 ..	25.1	5.0	20	30.3	7.0	23
13th April 1954 ..	17.1	7.9	46	—	—	—
13th April 1954 ..	19.3	6.4	33	40.0	9.9	25
10th July 1953 ..	15.4	4.1*	27	4.4	0.5*	11
5th August 1954 ..	21.8	1.2	6	—	—	—
18th August 1954 ..	22.9	3.2	14	—	—	—

All differences, except those marked with an asterisk, were significant at the 1 per cent probability level.

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By lowering mechanical strength, increase in stem length will probably be more often deleterious than useful under practical conditions. For instance, the chances of being beaten down will be seriously increased in a cereal crop with abnormally long stalks. Where the crop is a biennial such as cabbage or lettuce, harvested in the rosette stage, stimulation of stem production, i.e. of 'bolting', would be obviously undesirable. There is, however, one instance where it might be a useful effect; that is in those crops, such as flax and hemp, where fibres are extracted from the stem. F. Lona and A. Bocchi [24] have shown in laboratory experiments that both internode length and stem length of hemp is increased by gibberellic acid, but it is not known whether such effects could conveniently be produced under field conditions, nor how the quantity and quality of the fibre would be affected.

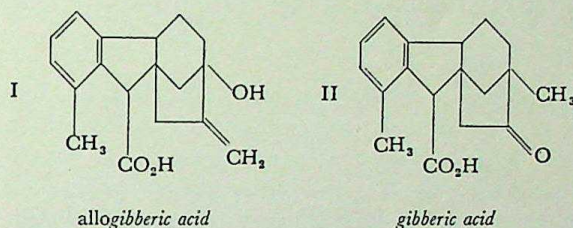
Earlier flowering of biennial plants might be useful in production of the seed of certain crops, but it is not yet known whether Lang's laboratory experiments with *Hyoscyamus* can be repeated on a field scale with other biennials. Similarly, no practical experience in connection with dormancy breaking has been reported. We may therefore conclude that such field experiments as have been carried out do not yet indicate any major use for gibberellic acid in agricultural practice and that far more field experimental work will be needed before a sound assessment of the prospects can be made.

CHEMISTRY OF GIBBERELIC ACID

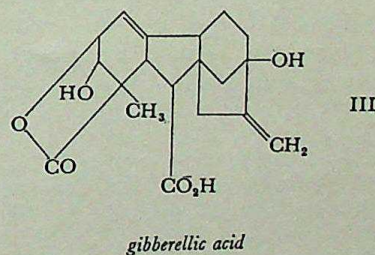
Gibberellic acid is a colourless monobasic carboxylic acid, melting with decomposition at 233–235°C; it is optically active ($[\alpha]_D^{20} + 92^\circ$). Analysis and molecular weight determination show its formula to be $C_{19}H_{22}O_6$ [25]. It is evidently a dihydroxy acid, for it forms monoacetyl and diacetyl derivatives each of which yields a monomethyl ester, as does the acid itself. If the acid is allowed to stand with excess of alkali at room temperature a second equivalent of alkali is consumed: this, considered together with the fact that the infra-red spectra of the acid and its derivatives in dioxan solution show strong bands at 1780 cm^{-1} , indicates the presence of a saturated γ -lactone ring. Microhydrogenation shows the presence of two ethylenic bonds. The above evidence accounts for all the oxygen atoms and indicates that gibberellic acid is a tetracyclic dihydroxylactonic acid.

Further information about the ring system has in the main been gained from study of two pro-

ducts of acid hydrolysis. Mild acid hydrolysis (normal hydrochloric acid at 20°C) of gibberellic acid yields, among other products, *allogibberic acid* ($C_{18}H_{20}O_3$), together with one molecule of carbon dioxide: if the hydrolysis is conducted at 100°C the *allogibberic acid* is isomerized to *gibberic acid*. The available evidence, summarized below, allows the structure of these two hydrolysis products to be expressed with a good deal of confidence as:



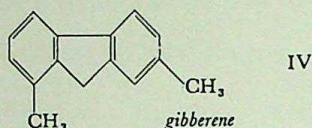
Determination of the structure of these two derivatives, however, does not make it possible to assign a definite structure to gibberellic acid itself. The evidence is consistent with the structure III, but other possibilities which have been summarized elsewhere [26] cannot at present be excluded. The stereochemistry of gibberellic acid and its structural relationship to gibberellins A_1 and A_2 remain to be elucidated.



Gibberic acid. The formation of an oxime, a methyl ester, and an oxime ester shows this to be a keto acid; the infra-red spectrum, with a strong band at 1741 cm^{-1} , indicates that the keto group is present in a five-membered ring. It contains no ethylenic bonds, but the ultraviolet spectrum is consistent with the presence of a benzenoid ring.

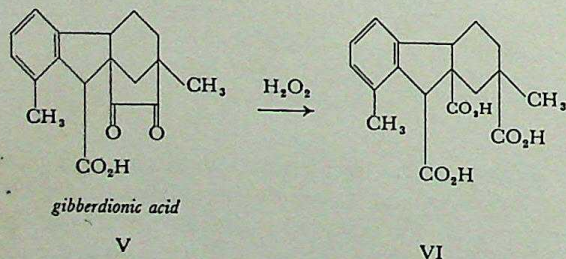
Oxidation with selenium dioxide yields *gibberdionic acid*, $C_{18}H_{18}O_4$, a yellow cyclic α -diketone. The ultraviolet absorption spectrum of this is almost identical with that of gibberic acid in both ethanolic and sodium hydroxide solution. This is

significant, for α -diketones in which adjacent carbon atoms carry hydrogen readily enolize and in consequence have an ultraviolet spectrum characteristically different from that of the parent monoketone. Gibberic acid therefore contains a $-\text{CH}_2-\text{CO}-$ grouping so situated in a five-membered ring that enolization is precluded.



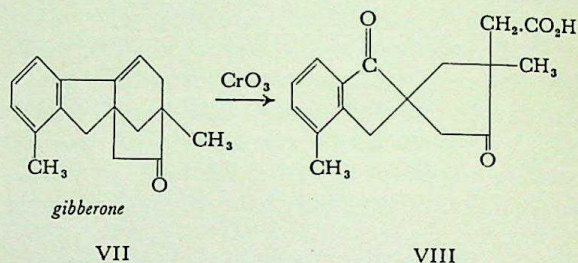
Oxidation to benzene-1:2:3-tricarboxylic acid and selenium dehydrogenation to a hydrocarbon, gibberene, which has been shown to be 1:7-dimethylfluorene (IV), establishes the presence of the 5:6:7:8:12:13-hexahydro-1:7-dimethylfluorene nucleus. Gibberene itself has been unambiguously synthesized [27] from 2-amino-5-methylbenzoic acid and *o*-tolyl magnesium bromide. The suggestion [28] that an acid obtained from gibberene might be fluorenone-4:5-dicarboxylic acid must now be discarded [29].

Evidently no skeletal rearrangement occurs during the selenium dehydrogenation, because gibberene is also obtained by mild dehydrogenation of the tricarboxylic acid (VI) formed by oxidation of gibberdionic acid (V) with alkaline hydrogen peroxide. The selenium dehydrogenation of gibberic acid must therefore involve elimination of the $-\text{CH}_2-\text{CO}-$ bridge, and so the methylene group of this bridge is attached to a quaternary carbon atom.



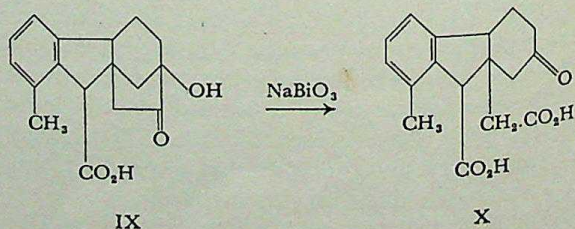
The position of the methylene carbonyl bridge in gibberic acid is finally determined by the following series of reactions. Oxidation by permanganate yields dehydrogibberic acid, the ultraviolet spectrum of which indicates the presence of an ethylenic bond conjugated with the benzene ring.

This acid can be decarboxylated to form a ketone, gibberone, with a five-membered ring. The latter retains the conjugated double bond, the position of which must be as in (VII), since oxidation with chromic oxide yields an alkali-stable indanone carboxylic acid. The constitution of this (VIII) can be deduced from the fact that on permanganate oxidation 3-methylphthalic acid and β -methyltricarballic acid can be isolated.



Finally, the position of the carboxyl group in gibberic acid is established by dehydrogenation of methyl gibberdionate to methyl 1:7-dimethylfluorene-9-carboxylate identical with a synthetic specimen.

Allogibberic acid. This contains a benzenoid ring, a terminal methylene group, and one hydroxyl group which appears to be tertiary both because it is difficult to acylate and because dihydroallogibberic acid cannot be oxidized to a ketone. A Wagner-Meerwein rearrangement would explain the isomerization to gibberic acid. The position of the carboxyl group is as in gibberic acid, since methyl allogibberate yields methyl gibberate with dilute acid. Ozonolysis of allogibberic acid yields formaldehyde and a five-ring α -ketol (IX) which sodium bismuthate will oxidize to a dicarboxylic acid (X). The dicarboxylic acid, on selenium dehydrogenation, yields 7-hydroxy-1-methyl-fluorene identical with a specimen obtained synthetically from 2-amino-5-methoxybenzoic acid by a route similar to that used for the synthesis of gibberene [30].



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Book reviews

ORGANIZATION OF SCIENCE

The Organisation of Science in England, by D. S. L. Cardwell. Pp. ix + 204. William Heinemann Limited, London. 1957. 18s. net.

Mr Cardwell has performed a very useful service. He has recorded the development of scientific and technical education in England from 1800 to the end of the first world war. His chronicle is well documented; he has given accurate summaries of the chief features of this confused and fascinating story; and he has picked out the names of some of the men who should be honoured as the pioneers of education in science—Brougham and Birkbeck, Babbage and Lyon Playfair, James Hole and Booth. There is a good account of the part played by the mechanics' institutes, the Royal Society of Arts, the British Association, and the select committees and royal commissions which followed the Great Exhibition of 1851.

Mr Cardwell has wisely refrained

from too many explanations or rationalizations of the facts in his chronicle. Almost every page raises questions. Why did technical education in England develop so differently from that in Germany? Why, if technical education was so much more advanced on the Continent in the 1860s, did one find English craftsmen commonly employed in continental firms? Did the reluctance of Oxford and Cambridge to reform themselves in mid-century retard or accelerate the rise of provincial universities in England? And so on. It will need a much more thorough study (especially of foreign sources) than Mr Cardwell has succeeded in making, to answer such questions as these; but he has drawn attention to them, and that is a welcome and significant contribution.

The book so closely covers ground already treated by Professor Armytage in chapters 8–11 of his 'Civic Universities' that comparison is inevitable. Mr

Cardwell does not write with the same precision and clarity as Professor Armytage, nor does he display such an easy mastery over his facts. There are some minor and irritating sub-editorial inconsistencies, e.g. some names appear adorned with initials, titles, and even degrees; other names, entitled to all these embellishments, are not so favoured. A much more serious defect is that the index, which is an essential part of such a chronicle as Mr Cardwell's, is very poor. However, these are quibbles: the book is a very useful contribution to the history of education and the author is to be congratulated on reducing so much material to order in such a modest compass. E. ASHBY

RELAXATION METHODS

Relaxation Methods in Theoretical Physics, Vol. II, by Sir Richard Southwell. Pp. vi + 522. Clarendon Press, Oxford. 1956. 55s. net.

This is the second volume of a treatise of which Volume I was published in 1946. That volume dealt with plane potential problems, problems of conformal transformation, and problems involving boundaries or interfaces whose positions are not finally known. The present volume deals with a number of more difficult problems which could not be included in the earlier volume, since they had not been released from the restrictions of war-time secrecy. They relate to biharmonic analysis, to stress systems in solids of revolution, to eigenvalues, and to certain aspects of elastic stability; a number of interesting non-linear problems of elasticity, hydrodynamics, and plasticity are also dealt with. The present volume is of very great interest not only for the variety of important problems of mathematics and engineering which it considers, but for the technical advances in relaxation methods which it describes. The volume is beautifully printed and illustrated.

A certain air of sadness broods over this volume, in which the author seems at last to bid farewell to his readers. No one is better entitled to assert that his purpose is at last achieved, but it is greatly to be hoped that Sir Richard Southwell will find new worlds to conquer and further works to publish.

G. TEMPLE

SOLAR PHYSICS

The Sun, by G. Abetti, translated by J. B. Sidgwick. Pp. 336. Faber and Faber, London. 1957. 63s. net.

Since Professor Abetti's book *Il Sole* was first published in 1934 it has provided the most complete account available of the complicated facts about the spots and other features of the solar surface, and about their changes of form and position. It has become a standard work of reference, of which an English translation was published in 1938.

A second Italian edition, revised and enlarged, appeared in 1951. During the interval between the two editions there were great advances in solar physics. In particular, the importance and significance of solar flares have been recognized and they have been intensively studied; solar radio emissions from the quiet sun and the enhanced emissions from disturbed areas have been discovered and investigated; the origin of the coronal spectral lines has been found and much study has been devoted to the physics of the corona;

much has been learnt about the constitution of the Sun and about the source of stellar energy.

The publication in English of a translation of the second edition is very welcome. Progress in solar research has been so rapid that some revision of the work, and additions to it, were needed: this has been carried out by Professor Abetti for the purpose of the new translation. The new edition provides an up-to-date survey of what is known about the Sun. It can be read with profit by both the amateur and the professional student. The value of the book is much enhanced by the numerous plates, which have been carefully selected to illustrate observational equipments and various solar phenomena. There are, in addition, 97 text figures. H. SPENCER JONES

MODERN PHYSICS

An Approach to Modern Physics, by E. N. da C. Andrade. Pp. ix + 232. G. Bell & Sons Ltd., London. 1956. 25s. net.

This volume is an extensively revised and enlarged version of Professor Andrade's book published in 1930 under the title 'The Mechanics of Nature', which has gone through several editions. The text is now about twice as long as the original and considers all the advances of the past thirty years.

The work is presented as a series of 'talks'—one might even call them intellectual conducted tours—on the various branches of physics, which rapidly survey all the landmarks in physics from the origins of modern science up to the present. Possessing a deep knowledge of his subject and combining the experience of a physicist of great distinction with a very wide general culture, Professor Andrade has interspersed his account, which is not without touches of humour, with penetrating and thought-provoking observations, with interesting comparisons, and with informative quotations from other writers of authority. It is surprising to learn, for example, that Newton, with prophetic intuition, had foreseen the danger to humanity of the discovery of means of transmuting the elements.

The scheme of the work unfolds methodically, the order being both logical and chronological. After having reviewed the role of physics and the precise significance to be attributed to its discoveries and theories, Professor Andrade deals in turn with heat and energy, sound and vibrations, light and radiation, electricity and charged parti-

cles, solids and liquids, quantum theory, the structure of the atom, the structure of the nucleus, applications of nuclear energy, and lastly with Heisenberg's uncertainties.

The reader is thus gently led by a firm and skilful hand towards the more abstruse branches of physics, finally reaching the extraordinary discoveries of contemporary science. He will be impressed by the clarity and originality of the exposition, by the ease with which the author introduces him to the most difficult problems, and by the talent which he displays in revealing hidden relationships. We found particularly interesting the chapter he devotes to solids and liquids, a subject which he knows most intimately and to which he has made many noteworthy personal contributions, as well as the two chapters dealing with nuclei and applications of nuclear energy.

Recalling that ethical principles possess a permanence never shared by the concepts of physicists, he wisely stresses that it would be vain to base definitive philosophical doctrines on the always provisional results of science.

Professor Andrade's book is a fine work, which presents us with a splendid panorama of the brilliant progress of modern physics and bears witness to the balance and clarity of his thought, based on a wide fund of experience and knowledge. LOUIS DE BROGLIE

ANALYSIS OF DEFORMATION

Analysis of Deformation, by K. Swainger. Vol. III, Fluidity. Pp. xxvii + 266. Chapman and Hall Limited, London. 1956. 65s. net.

This volume treats deformation from the viewpoint of fluidity. It is used to provide a platform for the author's critical views on the classical approach and for the presentation of a new theory of fluid motion. The chief feature of this theory is the rejection of the non-linear convective acceleration term in the Euler form of the motion stress equation.

After an introductory chapter there follows an exposition of the mathematical formulation of both the author's theory and the classical theory. The remainder of the book, apart from some unnecessary mathematical appendices, is concerned with applications to topics such as viscous flow and stress-fluidity.

Most of the remarks made in the review of Volumes I and II of the author's series under the present title are still valid and hardly need reiterating, but it is worth noting that on this

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occasion as much as seven pages are required to record the 'principal notation'. This is an indication of the difficulty of comprehending the many equations which appear so profusely throughout the book. The author states that 'it was tempting to go on expanding the work...' and hints at a second edition. It would perhaps have been better to have delayed writing this book, and the earlier volumes, until the subject matter had settled down into a more stable and acceptable state.

L. S. GODDARD

MAGNETOHYDRODYNAMICS

Magnetohydrodynamics, by T. G. Cowling. Pp. viii + 115. Interscience Publishers Inc., New York; Interscience Publishers Limited, London. 1957. Hard covers, \$3.50; paper covers, \$1.75 net.

The average graduate in physics usually knows a little about the problem of the origin of the Earth's magnetic field, and he may have read something concerning the dynamo theory which is used to explain its maintenance. It is, however, rather unlikely that he will have appreciated that this theory is but one example of the many applications of magnetohydrodynamics, the study of the motion of electrically conducting fluids in the presence of magnetic fields. But if he will turn to this excellent little book he will be rewarded by a glimpse of many fascinating applications of it to problems of sunspot equilibrium, solar streamers and filaments, stellar rotation, magnetic variable stars and ionized gases, and an account of the author's own attempts to explain the darkness of sunspots by magnetic inhibition of convection. He will read of experiments on moving mercury and liquid sodium and perhaps consider that here is a relatively new branch of science which well deserves further study.

L. F. BATES

PHYSICS OF THE SOLID STATE

Introduction to Solid State Physics (second edition), by Charles Kittel. Pp. xvii + 617. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1956. 96s. net.

'To see a World in a Grain of Sand...' Solid-state physics has a feast for every scientific taste. The natural historian may collect growth patterns on crystals. The 'Sceptical Chymist' has leave to doubt whether Brillouin zones really explain complex alloy phases with 57 atoms per unit cell. For those who love computing, there are enough sums in

the calculation of energy bands to fill all the MANIACS, WHIRLWINDS, and such mathematical toys in the world. Mathematical elegance may flirt with the Ising model and lattice spectra. Superconductivity is a challenge to the most powerful intellects of theoretical physics. Ingenuity may play with tin whiskers and dislocation network.

Ever since its publication, only three years ago, 'Kittel' has been (especially in the United States) the principal entry visa into this land of riches. The new edition has been enlarged in size by about one-half (and in price by rather more). Many sections have been expanded to include new material or to improve the argument. The order of topics has been altered, and several completely new chapters have been added. The work still has the lucidity, the straightforward and brisk style, and the flair for a simple 'physical' explanation, that graced the original. There are a few points of detail open to dispute, and there are some signs of haste in arranging the text and correcting the proofs; but these are minor blemishes in a thoroughly useful book, indispensable for learning, for teaching, and for recalling what every solid-state physicist knows.

J. M. ZIMAN

FIBRE PHYSICS

The Mechanical Properties of Textile Fibres, edited by R. Meredith. Pp. xii + 333. North-Holland Publishing Company, Amsterdam. 1956. 61s. net.

During the past few years the subject of fibre physics has grown in scope and importance and is attracting the attention of an increasing number of fibre scientists. This monograph forms one of a series covering the rheology of deformation and flow in natural and synthetic substances, and Dr Meredith and his co-authors are to be congratulated on a most serviceable and worthwhile undertaking. This is the first book of its kind to set out to interpret in some detail the mechanical properties of fibres in relation to what is known about their structure.

The subject is developed from basic principles for the three main groups of textile fibres: cellulose, proteins, and synthetic fibres. After dealing briefly with the structure of these groups, the authors trace and relate the structural features with such important aspects of fibres as relaxation and creep, stress-strain relationships, strength, dynamic and mechanical properties, and resilience. The treatment is not encumbered

with unnecessary detail. All who are interested in the field of fibre physics will find this book very useful. R. HILL

TRANSPORT PROCESSES IN CHEMICAL MANUFACTURE

Transport Processes in Applied Chemistry, by R. C. L. Bosworth. Pp. x + 387. Sir Isaac Pitman and Sons Limited, London. 1956. 84s. net.

This is the third book by the author to deal with aspects of physics which are of fundamental importance in many of the operations of industrial chemistry.

His second book, published in 1952, reviewed recent developments in heat transfer and dealt with this as a transport process basically similar to the diffusion of matter, momentum, and electric charges. The present volume extends this treatment, dealing with a wider range of processes and carrying them further, even to including complete industrial operations. The author deals with the significance and mechanism of processes of transport by molecular motion, and with radiant and convective transfer. There are chapters on turbulent and inter-phase transport, irreversibility, feedback, cascade operations, and chemical similarity. Methods of measuring the efficiency of transport processes are formulated, and a final chapter on the wider aspects of transport processes includes considerations of the driving force and ultimate cost of industrial operations and the efficiency of utilization of energy.

Each chapter is a useful, if necessarily short, review of its particular subject. This, coupled with the unified mathematical treatment of a very wide range of transport processes, should make this book of great value to applied chemists and chemical engineers in universities and industry who wish to gain a deeper, more basic insight into these aspects of industrial operations than is obtained by the classical approach of unit operations.

G. M. NICHOLLS

COLORIMETRIC ANALYSIS

Metallurgical Analysis by means of the Spekker Photoelectric Absorptiometer, by F. W. Haywood and A. A. R. Wood. Pp. viii + 292. Hilger and Watts Limited, London. 1956. 40s. net.

First published in 1944, this book on colorimetric analysis has been completely revised and brought up to date by A. A. R. Wood in the light of the many recent advances in this field. The writer was associated with the design

and development of the Spekker apparatus and is author of several papers on methods suitable for the analysis of specific elements. The first part of the book deals with the principles of colorimetric analysis, and includes details of the construction, operation, and maintenance of two models of the Spekker photoelectric absorptiometer. In the second part, selected methods of analysis are given for elements usually found in alloys based on aluminium, copper, magnesium, and zinc respectively, and in the more common steels. An extensive bibliography, covering the period 1940-1954, includes original papers on the determination of twenty-two elements by colorimetric analysis using the Spekker absorptiometer. An appendix contains some useful information and includes tables giving the average compositions of various metals and alloys which form suitable chemical standards for this type of analytical work. As a handbook it should be indispensable in all laboratories using the Spekker apparatus. B. W. MOTT

COMPLEX METAL HYDRIDES

Reduction with Complex Metal Hydrides, by N. G. Gaylord. Pp. xvi + 1046. Interscience Publishers Inc., New York; Interscience Publishers Limited, London. 1956. \$15 net.

The reduction of organic compounds with lithium aluminium hydride was first described just over ten years ago. Organic chemists were quick to realize the significance of this reagent, which could be used, for instance, to reduce an ester to an alcohol in cold ether. During the past decade the uses of lithium aluminium hydride and related compounds such as sodium borohydride have been manifold, and there has been a growing need for a comprehensive monograph about them. The need is now satisfied by this book, which covers, up to January 1953, in a complete and often critical manner, the preparation and reactions of the complex metal hydrides, including the less common ones such as magnesium aluminium hydride and lithium gallium hydride.

The author deals systematically with the individual hydrides and their reactions with inorganic reagents and with the various groups of organic compounds, concluding with chapters on the experimental handling of the hydrides. No reference will be found to the more recent developments of hydride chemistry, but even so the book

will be a necessity for organic chemical laboratories. Its price is unfortunately such that very few chemists will be able to afford a personal copy.

T. G. HALSALL

ACRIDINES

Acridines, by R. M. Acheson. Pp. xii + 409. Interscience Publishers Inc., New York; Interscience Publishers Limited, London. 1956. \$12.50 net.

This is the ninth volume of the Interscience series of monographs on 'The Chemistry of Heterocyclic Compounds', and a single reading suggests that it is a praiseworthy book. The material is well arranged in nine chapters dealing with the main group of acridine derivatives, and including chapters on the acridine alkaloids, the absorption spectra of acridines (by L. E. Orgel), and biologically active acridines.

Comparison with Professor Adrien Albert's monograph published in 1951 is inevitable. The two books are differently arranged and completely different in their approach to the subject. The earlier volume contained experimental details of many preparations, and was obviously the work of one who had been long immersed in the subject. Acheson's book is much more the formal monograph, but has the advantage of covering the literature up to 1954.

Acheson devotes seven full pages to the argument about nomenclature and numbering, and reproduces a graph comparing the frequencies with which Graebe's and Richter's numbering systems have been used. Albert used Richter's method, but Acheson, on the basis of his statistical approach, decided on Graebe's system, which is now used by *Chemical Abstracts*.

One may regret the duplication of effort represented by the existence of two works on acridines, but in the outcome it is fortunate that they are both good.

K. SCHOFIELD

INDEX OF CRYSTALS

The Barker Index of Crystals, Vol. II, by M. W. Porter and R. C. Spiller. Pt. 1, Pp. 383; Pt. 2, Pp. 1800; Pt. 3, Pp. 1772. W. Heffer and Sons Limited, Cambridge. 1956. £10 net.

The Barker Index makes it possible to identify a substance by comparison of crystal angles with known values. Over half the measurements available are of monoclinic crystals, and Volume II which deals with these is correspondingly large. To arrange 3572 substances

in order of increasing angle αm between the faces (100) and (110), that is, a 'setting', crystallographic axes, orientation, and indices must be chosen. Since face development controls the setting according to stated rules, varying crystal habit may require alternative settings. This happens for about a third of the first 150 substances.

Apart from possible use for analysis, the volumes form a valuable collection of morphological data. They deal with all monoclinic crystals in Groth's *Chemische Kristallographie*, and some others. The information is authoritative, since, in the course of setting, original investigators' mistakes in calculation, which are numerous and often copied into Groth, have been found and corrected.

Tables of refractive indices, densities, and melting points, with indexes in several forms and references to the index of X-ray data of the American Society for Testing Materials, are valuable added information.

An introduction by M. H. Hey supplements the accounts of Volume I (Part 1) by describing the special applications of the Barker method to the monoclinic system.

An important addition, the lack of which was felt when Volume I appeared, is a single page of brief directions suitable for experienced crystallographers.

The index is reproduced by a photographic method, and the covers are appropriately decorated with a drawing of a Tutton salt. H. M. POWELL

GEOMAGNETISM

Beiträge zur Geschichte der Erkenntnis des Erdmagnetismus, by H. Balmer. Pp. 892. Verlag H. R. Sauerländer & Co., Aarau. 1956. Sw. Fcs. 31.10 net.

This 892-page work is an enlargement of a thesis for a doctorate, the first part giving a general account of the history of geomagnetism from the earliest times to the present day. The second part contains translations of most of the classics of the subject into German, including the letter of Petrus Peregrinus, the whole of Gilbert's *De Magnete*, Stevin's *Hauenvinding*, some of Kepler's letters, and much else. This section will be of great value to those whose first language is German, though most of it is already available in English or French. The third section discusses beliefs about two persistent magnetic myths—the existence of an enormous magnetic mountain and the possibility of communicating over

great distances by magnets. There are also 200 pages of brief biographies of about 950 people concerned with the history of geomagnetism, and an account of the development of the subject in Switzerland.

The author rightly calls his work a 'collection' rather than a 'history'; it contains all kinds of interesting things put together without any very profound discussion. The story of the Chinese knowledge of the declination in the twelfth century is, for instance, accepted without a mention of the doubts that most modern commentators have felt about the matter. There is a curious lack of reference to modern works on the history of science—the account of Halley, for example, is largely based on Humboldt's *Kosmos* and does not mention MacPike's books. Silvanus Thompson's translation and commentary on *De Magnete* also are not mentioned.

E. C. BULLARD

EFFECTS OF RADIATIONS

Actions chimiques et biologiques des radiations, *edited by M. Haissinsky*. Pp. vi + 221. Masson et Cie, Paris. 1956. Bound, Fcs. 3400; paper covers, Fcs. 2800 net.

The second of this series of monographs consists of three contributions. W. Mund gives an account of the chemical effects produced by the passage of ionizing radiations through gases and includes two detailed special sections on inorganic and organic reactions induced by radiation. M. Ageno describes luminescent phenomena produced by high-energy rays and presents recent methods and results in the study of scintillation phenomena. N. Miller's introduction to radiation dosimetry is extremely well set out and should be of great value to workers in many fields. An admirable feature in all the articles, particularly that by M. Ageno, is the close link that is maintained between theory and practice. Of particular importance is the stress laid on the methods used in the various fields, since by this means the reader can appreciate more clearly some of the difficulties of the problems involved and is at the same time provided with useful practical information. The book has an appendix containing conversion factors for physical constants and practical details for radiator dosimetry. One slight criticism is that there is a tendency for the text to invade some of the figures. Otherwise, the monograph is a useful addition to any scientific library.

D. B. ROODYN

BIOCHEMISTRY OF LIPIDS

Biochemical Problems of Lipids (Proceedings of the Second International Conference held at the University of Ghent, 27th to 30th July 1955), *edited by G. Popjak and E. Le Breton*. Pp. xvi + 505. Butterworths Scientific Publications, London; Interscience Publishers Inc., New York. 1956. 70s. net.

Knowledge of the chemistry and biochemistry of lipids has grown rapidly within the last five years, mainly thanks to the new tools of paper and gas-liquid chromatography and the discovery of coenzyme A and its role in the metabolism of fatty acids. The enzymes responsible for the β -oxidation and for the synthesis of fatty acids have been identified and isolated, and this has led to detailed knowledge of the intermediary metabolism of fatty acids. The biochemistry of phospholipids and of fat transport and the study of nutritional aspects (especially of the unsaturated fatty acids) have also advanced considerably. All these developments and many other aspects are summarized and discussed in the present volume. It contains 69 papers (mostly in English, a few in French or German), together with a brief record of the discussions which followed the presentation of the papers. Many leading workers in the field have contributed, and the result is an authoritative survey of recent and current research on the biochemistry of lipids.

H. A. KREBS

ENZYMES AND VIRUSES

Enzyme Antigen and Virus, *by Sir Macfarlane Burnet*. Pp. viii + 193. Cambridge University Press, London. 1956. 18s. net.

Sir Macfarlane Burnet is well known for his contributions to animal virology, and also for his provocative speculations on wider aspects of biology and medicine.

This book is an extension of the theories put forward in 1949 by Burnet and Fenner in their monograph 'The Production of Antibodies', and is an attempt to link antibody formation with recent knowledge on synthesis of adaptive enzymes and growth of viruses. In all three processes, the cell receives a stimulus which makes it produce a new type of protein. The argument is not always easy to follow, but it eventually leads the author to propose a general information theory based on macromolecular pattern, which he suggests will not be interpreted entirely by the techniques of the physicist and chemist.

The work will probably invoke criticism from experts in the various fields which the author covers, but a complacent acceptance of hypotheses based on slender evidence would be the last thing he desires, and it is in any event unlikely in a group of subjects advancing so rapidly. There can be few biologists who have the imagination and breadth of interest of Sir Macfarlane Burnet and could attempt a stimulating work of this kind.

M. STOKER

BOTANICAL ATLAS

Botanisk Atlas, *by O. Hagerup and V. Petersson*. Pp. 550. Ejnar Munksgaard, Copenhagen. 1956. Cloth bound, Dkr. 96; leather, Dkr. 125 net.

This is primarily a collection of drawings of plants which are native, or have been introduced, or have intruded themselves into Denmark. Many of them also occur in the surrounding countries and are common, for example, in southern England. Habit drawings are given of every plant. These are the work of Vagn Petersson and are executed in fine, clear outlines, usually with a minimum of shading. In general, they show the full characters of the plants unambiguously, but grasses, labiates, and others tend to be represented by little more than the inflorescence. The great majority of these drawings were done from living plants, but the potamogetons are from herbarium material. Very numerous enlarged drawings of details are provided by Olaf Hagerup in a style that groups well with the habit drawings. The subjects are chosen to illustrate not only diagnostic characters but also life forms and biological stages. In general they admirably fulfil their purpose, but it is surprising that no indication is given of their magnifications. Some pages are devoted to the general characters of the larger families such as grasses, orchids, and umbelliferae. The book is very elegantly produced on a large page, 11 × 8 in., allowing nearly life-size representation of most of the species. Botanists have much reason to be grateful to the authors.

W. O. JAMES

BOTANY OF TROPICAL CROPS

An Introduction to the Botany of Tropical Crops, *by Leslie S. Copley*. Pp. xv + 357. Longmans, Green and Company Limited, London. 1956. 37s. 6d. net.

Of a subject as many-sided as the botany of tropical crops, no textbook of convenient size can cover more than

selected aspects. Mr Cobley has chosen to present a wide survey, describing more than 150 species and referring briefly to as many again. Crops are grouped into twelve chapters according to their products—cereals, fibres, oil-seeds, and so on. The information given usually includes the systematic position of the plant, its origin and distribution in cultivation, a description of its gross morphology, and notes on uses. Other features of equal importance to the economic botanist, such as population structure and breeding methods, perforce receive scant attention or none.

Within the limits of his choice the author has done a workmanlike job and has been worthily supported by his publishers. The information given is accurate. The 82 plates and 66 figures are judiciously chosen adjuncts to the text. References are given at the end of each chapter for the student who wishes to go deeper.

Designed for students of agriculture, this book should be of particular value to the increasing number receiving training within the tropics.

E. E. CHEESMAN

HUMAN ANATOMY

Textbook of Human Anatomy, by J. D. Boyd, Sir Wilfrid Le Gros Clark, W. J. Hamilton, J. M. Toffey, Sir Solly Zuckerman, and the late A. M. Appleton. Pp. xii + 1022. Macmillan and Company Limited, London; St Martin's Press, New York. 1956. £5 net.

The conventional undergraduate course in human anatomy is invariably a main target for those who complain about the load of factual knowledge thrust on the unfortunate medical student of today.

This new textbook is an attempt to meet this criticism. In this it has succeeded, in part by omissions—for example, in the section dealing with the locomotor system, where much of the tedious detail of muscular attachments and of classical osteology has been left out—and in part by linking structure to function to produce a more readable and thus a more readily assimilated story—nowhere better illustrated than in Sir Solly Zuckerman's section on the ductless glands. Sir Wilfrid Le Gros Clark gives in the space of only 129 pages an excellent account of the central nervous system and successfully resists the temptation to omit nothing, although some may think that the reticular formation of the brain stem

has now qualified for rather more than the two lines allotted to it. Likewise there is a satisfactory and not too prolix account of the main features of the digestive system by Professor W. J. Hamilton which maintains the modern balance between macro- and microscopic anatomy. It seems to be impossible, however, for an anatomist to deal with the peritoneum other than in traditional fashion, deflecting it from here to there, so that the reader begins to feel in the centre of a maze that has no exit. There is no systematic treatment of embryology, but each section gives a brief outline of the relevant development.

The book is profusely illustrated by 796 half-tone drawings, some with colour, X-ray plates, and microphotographs, most of them of a high standard of excellence.

Although the authors claim with justice that they have eliminated much of the detail of classical anatomy, nevertheless this remains a heavyweight textbook, of over 1000 pages. The medical student will undoubtedly find it an interesting and profitable book, to be read and not to be used merely as a reference to supplement dissecting manuals and other short cuts to knowledge.

G. M. WYBURN

THE WORLD OF PLANKTON

The Open Sea: Its Natural History: The World of Plankton, by Alister C. Hardy. Pp. xv + 335. Collins, London. 1956. 30s. net.

Professor Hardy is known to his students as an enthusiast, and perhaps the greatest of his enthusiasms is the world of plankton. As might be expected from the occupant of the Linacre Chair of Zoology and Comparative Anatomy at Oxford University, the enthusiasm is well informed and not, like so much, misdirected. This is not to say that the book is perfect: enthusiasm leads to discursiveness, which, though it helps to hold the reader's interest, makes subsequent reference often difficult. When I first opened this book I felt that accurate photographs or line drawings would form more fitting illustrations than water-colours to a book of this nature, but as I read through and handled it I became a convert to Professor Hardy's mode of illustration. His water-colours do indeed give a far better impression of the living planktonic organisms than any photograph or line drawing could, while accurate detail is supplied by line

drawings and the excellent photographs of Dr D. P. Wilson. This general impression, combined with accuracy of detail, make the book an outstanding example of its kind, both for the general reader, for whom it is not too technical, and for the student, or indeed the university teacher.

D. B. CARLISLE

REPTILES

Reptiles, by Angus d'A. Bellairs. Pp. 195. Hutchinson's University Library, London. 1957. 10s. 6d. net.

Reptiles living today can be separated into four clearly defined classes: tortoises and turtles, the Tuatara, lizards and snakes, and crocodiles. Extinct forms reveal a far greater diversity of organization, and only by study of them is it possible to obtain a deeper insight into reptile anatomy. The most ancient reptiles appeared in the Carboniferous period. Reptiles flourished throughout the Mesozoic era, which lasted some 120 million years and is also known as the Age of Reptiles. Giant orders of reptiles disappeared towards the end of the Cretaceous period.

It needs considerable courage to produce a comprehensive survey of our knowledge of reptiles within a limited space. The author of this book performed this task with great skill. The reader is first made familiar with the leading anatomical and physiological features of the reptile body. A description then follows of the main classes of fossil and extant reptiles, a final chapter being devoted to the biology of lizards and snakes. The text is relieved by twelve figures and numerous illustrations, and a bibliography of the more important literature provides the interested reader with valuable hints for further study. We owe our thanks to the author for this work and hope that it will enjoy a wide circulation, particularly among students.

E. KUHN-SCHNYDER

PHARMACOLOGY

Medicinal Chemistry, Vol. III, edited by F. F. Blicke and R. H. Cox. Pp. vi + 346. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London. 1956. 84s. net.

This is the third of a series of publications whose object is to provide summaries of the biological properties of substances, particularly for those chemists and pharmacologists most concerned in the elaborating and testing of new drugs. It deals with Methadone

and related analgesics, quaternary ammonium germicides, non-mercurial diuretics, and analogues of physostigmine. The emphasis in these chapters is not so much on the chemistry and physiological action of these compounds as on methods of evaluating their activity and on the correlation of structure and activity. Almost two-thirds of the book is given up to tables relating the structure of compounds with their biological activity. This is the essential feature of the volume, for which reason it should be of value to those actively seeking new therapeutic agents. It should be noted, however, that most of the work which has been sifted and classified was published before 1953.

J. R. P. O'BRIEN

INDUSTRIAL CHEMISTRY

Guida dei principali prodotti chimici, Vol. I, by Cesare Ferri. Pp. xvi + 737. Nicola Zanichelli, Bologna. 1955. Lire 6000 net.

The very wide programme suggested by the title is achieved by alphabetical classification according to use. Under petrol additives, lead tetra-ethyl receives special attention, but stabilizers and anti-corrosives are not forgotten. Additives for lubricating oils and auxiliaries in paper and textile manufacture are reviewed, and there is a useful section on motor fuels. Catalysts are set forth in tables and specific ones are named for different processes, polymerization catalysts being discussed separately. There is a concise tabulated account of ceramics. Twenty-eight pages are devoted to a survey of modern dyes. Fuels of all kinds are described. Detergents, explosives, synthetic fibres, photographic chemicals, and pigments occupy the attention of other contributors. No fewer than 159 pages are devoted to pharmaceuticals, two authors sharing the work. The whole subject is well reviewed, and formulae are given for many of the more important antibiotics, vitamins, hormones, and antihistaminics.

Lubricants of all types are considered, and there are valuable summaries of their physical characteristics. Plastics are reviewed by means of a genealogical table.

There is unavoidably much variation in the treatment by individual collaborators, but this is preferable to the dull uniformity which might have resulted from a more highly planned effort. Regarded as a whole, this is a valuable work.

E. E. TURNER

CHEMISTRY AND TECHNOLOGY
OF WAXES

The Chemistry and Technology of Waxes (second edition), by A. H. Warth. Pp. vii + 940. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London. 1956. 144s. net.

This edition extends to over 900 pages and includes very full descriptive accounts of 'natural' (animal and vegetable) waxes; fossil, lignite and petroleum waxes; and 'synthetic' and compounded waxes of many kinds. There is a prefatory chapter on the chemical components of waxes (which, however, is almost wholly concerned with those of the natural ester-waxes), and two concluding chapters on analytical methods and on the technology of waxes and their uses in industry. The range of materials classified technically as waxes is admittedly very wide and in some ways ill defined; it is therefore all the more desirable that a book of this nature should be composed as explicitly and clearly as possible. Unfortunately the treatment is diffuse in many respects and this detracts from the value of a book which otherwise is a comprehensive and detailed survey of the many substances, natural or artificial, which have waxy properties, irrespective of whether they have so far found industrial applications.

Moreover, instances occur in which reports on waxes are included, both old and recent, with little critical comment on the probable relative accuracy of the sometimes divergent accounts. Thus on page 142 spermaceti is said to melt at 42-46° C and to contain 90 per cent of cetyl palmitate (m.p. 51.6°), whereas the figures on page 147 show that cetyl palmitate cannot amount to more than about one-third of the solid waxes of sperm head oil. Again, it is not sufficiently emphasized that the so-called waxes of Rhus and Myrica berries, and ucuhuba and murumuru 'waxes' (which are seed fats) are wholly glyceridic (fatty) in composition. Similarly, in the chapter on the chemical components of waxes there is some muddled, some probably inaccurate, and not a little superfluous information.

Apart from these defects—all the more unfortunate when dealing with a subject which is in itself both complex and ill defined—the book is a valuable addition to a technological field in which guidance by competent handbooks is still rather inadequate.

T. P. HILDITCH

CONSERVATION OF WORKS
OF ART

The Conservation of Antiquities and Works of Art, by H. J. Plenderleith. Pp. ix + 373. Oxford University Press, London. 1956. 63s. net.

This is a book that we have all been awaiting for twenty years. The author's experience of his subject is probably unique, and the book at once becomes the standard textbook and a classic. It is intended for the collector, the archaeologist, the museum curator, and the technician engaged in conservation, and one of the book's most striking features is the completeness with which it caters for the whole range of different attitudes to its very complex subject. A great many people, whatever their interests or discipline, will find it both absorbing and most useful.

The contents impress themselves in two main ways. First, there is the magnificence of the treasures that have passed through the hands of Dr Plenderleith and his associates at the British Museum Laboratory, and the variety and complexity of the problems they present. One feels envious of the opportunity, yet awe of the responsibility—but secure in the knowledge that the objects are in capable hands. Secondly, it is very refreshing to find the most specific sequestering agents jostled by the humble matchstick and spoon.

This kind of work involves electrical, chemical, and mechanical methods, and the best results are obtained by a judicious co-ordination of the three. Almost inevitably it follows that each problem requires highly individual attention. And here a warning: the deceptive ease of the description, and the clarity of the many tables and schemes of treatment, may mask the author's perhaps too quiet insistence on the need for skill and experience.

The book is written with care, taste, and wisdom: it leaves one feeling just the right mixture of respect and unsatisfied curiosity. With it the author firmly stakes his claim for his subject to be considered seriously as a branch of applied science.

L. BIEK

SIR ARTHUR EDDINGTON

The Life of Arthur Stanley Eddington, by A. Vibert Douglas. Pp. xi + 207. Thomas Nelson and Sons Limited, London. 1956. 25s. net.

Arthur Stanley Eddington was essentially a thinker, not a man of action.

It is much more difficult to write the biography of a man whose life has been spent largely in his study than that of a man who has played a prominent part in affairs. Dr Vibert Douglas has succeeded admirably in her account of the life, the scientific work, and the philosophy of a man who was quiet, reserved, and undemonstrative, and who never sought the limelight.

An excellent account is given of the course of Eddington's scientific work on stellar movements, stellar structure, and stellar physics, on relativity, and on fundamental theory. Eddington was the first person in Great Britain to realize the importance and significance of general relativity, and his exposition of the theory did much to secure its acceptance. He was, incidentally, the leader of one of the two British expeditions which in 1919 provided the first verification of the predicted deflection of rays of light in a gravitational field. Eddington combined an appreciation of the problems of observational astronomy with a remarkable physical intuition and great mathematical ability.

By his work on stellar structure, the internal constitution of the stars, and the nature of interstellar matter, Eddington was the pioneer in what has become an important branch of modern astronomy. The meetings of the Royal Astronomical Society, at which these results were expounded, were full of interest and are vividly described.

Eddington exerted a great influence on current thought through his interpretation, by lectures and by writing, of the new ideas that were revolutionizing man's conception of the universe. Miss Douglas gives an excellent account of the development of his philosophical ideas.

Though the book will have its greatest appeal to the physical scientist, all who follow the development of scientific thought will find the book of much interest. H. SPENCER JONES

CHINESE SCIENCE

Science and Civilisation in China, by Joseph Needham. Vol. II, History of Scientific Thought. Pp. xxii + 696. Cambridge University Press, London. 1956. 80s. net.

The days of encyclopaedism have gone, but persons still appear with encyclopaedic minds and extraordinary industry, as is shown by the bibliography (pp. 585-683) of this volume,

which endeavours to survey Chinese philosophies and discover their influence on the development of Chinese science and technology.

Only recently, however, have specialists with modern training begun working on Chinese philosophies. The first really good history of Chinese thought, that by Feng Yu-lan, appeared only in 1934 and its complete English translation in 1953. Classical Chinese is, moreover, such a concise language that one must first understand a philosophy before translating it! Needham, for example, accepts the following (p. 460) as the translation of the first sentence in a famous Chinese text: 'That which has no Pole! And yet (itself) the Supreme Pole!' I would prefer to translate: 'The Unlimited is the same as the Absolute.' Obviously much work still needs to be done on this philosophy, that of the great Chou Tun-i, before attributing to him a premonition of negative and positive electricity (p. 467).

Against some of Needham's theses there will be strong reaction. Wang Chhung (pp. 368-86) was hardly 'one of the greatest men of his nation in any age' (p. 368). He merely offered a very readable, and partly superstitious, version of the thorough-going naturalism he derived from Hsün Tzu, through his teacher Pan Piao, the father of the great historian. Wang Chhung shows few philosophic originalities, while Hsün Tzu, whom Needham misprizes (pp. 26-29), was one of the dominating influences throughout all of Confucianism. If naturalism promotes science, as Needham assumes, Hsün Tzu was the more scientific.

Although much in this book is inevitably tentative, it contains certain very good discussions. The comparison of the Greek and Chinese ladders of souls (pp. 21-26) is interesting. There is a very good account of Taoism (pp. 33-164), in which there is pointed out both the connection and the lack of connection between this cult and Chinese science. Needham's account of the Later Mohists (pp. 171-84) is excellent. So is his discussion of Tsou Yen (pp. 232-73). Although Needham recognizes that Tsou Yen was not postulating any 'elements' in our sense of the word but rather five 'forces' (p. 244, line 13), he nevertheless still calls them 'elements'. His belief that the modern philosophy of organism is derived, through Leibniz, from Chinese thought (pp. 279-303) is possible, but

the relationship appears to me quite unproven. Leibniz was a thinker who required no Chinese stimulus for original ideas. Needham's best worked out section is his discussion of natural law (pp. 518-83).

This book is a highly praiseworthy attempt at a synthesis for which the necessary spadework is as yet mostly not done.

HOMER H. DUBS

HISTORY OF IRON AND STEEL

Réaumur's Memoirs on Steel and Iron, translated by Anneliese Grünhaldt Sisco. Pp. xxxiv + 396. The University of Chicago Press, Chicago. Cambridge University Press, London. 1956. 45s. net.

The translation of Réaumur's famous essays on iron and steel of 1722 is of particular value, since no English translation of the complete memoirs existed prior to the present publication. The translation is preceded by an introduction, in which Professor C. S. Smith discusses the significance of Réaumur's work and the background of metallurgical science against which he wrote. R. A. F. de Réaumur (1683-1757), commonly known today by his thermometric scale, was interested in all branches of pure and applied science. His interest in iron and steel began about 1716. It bore fruit in the present treatise of 1722 and a few more metallurgical memoirs read before the French Academy in the following four years, after which he published nothing more on metals. In this short period he made very important contributions to industrial technology. His ideas concerning iron and steel, made known in his memoirs of 1722, 'amounted to pre-science', representing a remarkable anticipation of modern knowledge, as Professor R. F. Mehl ('A Brief History of the Science of Metals', pages 5-6, New York, 1948) worded it. In his discussions of the grain size of cemented steel Réaumur anticipated many of the modern American studies of austenite grain size. One of Réaumur's principal inventions, a method of making malleable cast iron, may have been a re-invention of an earlier process patented in 1671 and invented by the ingenious Prince Ruprecht von der Pfalz, who through his mother was a grandson of James I of England. The Prince's and Réaumur's inventions both fell into oblivion, but were resurrected in England shortly after 1800.

H. R. SCHUBERT

Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

Recent Advances in Science: Physics and Applied Mathematics, edited by M. H. Shamos and G. M. Murphy. Pp. xi + 384. New York University Press, New York; Interscience Publishers, New York and London. 1956. \$7.50 net.

This is a collection of reports by twelve distinguished American scientists on recent developments in their own fields of physics and applied mathematics. It is a product of the First Symposium on Recent Advances in Science, held at New York University early in 1954. Although it is assumed that the reader has had some general scientific training, no specialized knowledge of the subjects discussed is assumed.

Electrochemistry: Principles and Applications, by E. C. Potter. Pp. xii + 418. Cleaver-Hume Press Ltd., London. 1956. 50s. net.

This is a comprehensive textbook, with the emphasis laid on principles and their relationship to general applications, designed for both the student and the electrochemical specialist. A knowledge of mathematics and chemistry at roughly the level of the first university year is assumed. There are numerical examples to demonstrate some of the theoretical concepts, and a short bibliography.

Automation: its Purpose and Future, by Magnus Pyke. Pp. 191. Hutchinson's Scientific and Technical Publications, London. 1956. 16s. net.

Opinions vary widely about the speed and extent with which automation will be introduced into industry, but there is no doubt that it is a development that will have far-reaching consequences. This book is principally for the general reader, and sets out both to describe what has already been achieved by means of automation and what can reasonably be expected of it in the fairly near future. There is some discussion of the social consequences of automation, which are certain to play an important part in determining the nature of its application.

The Geographer as Scientist, by S. W. Wooldridge. Pp. xii + 299. Thomas Nelson and Sons Ltd., London. 1956. 35s. net.

This is a collection of some sixteen lectures and papers prepared by Professor S. W. Wooldridge during twenty-five years of active teaching and research. The selection has been carefully made in order to illustrate the author's views on fundamental questions relating to the scope and nature of geography.

The Friendly Fungi, by C. L. Duddington. Pp. 188. Faber and Faber, London. 1957. 21s. net.

This book, written principally for the general reader, represents a new approach to the problem of the eelworm, one of the most serious of agricultural pests. It describes certain easily cultivated fungi that attack eelworms, and the attempts that have been made to use these fungi to attack the pest in the field.

Fibres, Plastics and Rubbers, by W. J. Raff. Pp. xvi + 400. Butterworths Scientific Publications, London; Academic Press Inc., New York. 1956. 63s. net.

This is a well-documented reference book intended for those engaged in industrial research and development. It lists, in a form suitable for ready reference, a very great deal of information on the chemical, physical, and general properties of all the most common high polymers, both natural and synthetic. It concludes with a short history of polymers.

Records and Research in Engineering and Industrial Science (third edition, rewritten and enlarged), by J. Edwin Holmstrom. Pp. xii + 491. Chapman and Hall Ltd., London. 1956. 60s. net.

The vast and rapidly growing extent of technological literature makes it increasingly difficult to find information that has already been recorded. This book, by the officer of UNESCO responsible for questions of scientific documentation and terminology, is a detailed guide to the sources and recording of all kinds of technical information.

Vapour Phase Chromatography, edited by D. H. Destry and C. L. A. Harbourn. Pp. xv + 436. Butterworths Scientific Publications, London; Academic Press Inc., New York. 1957. 70s. net.

The book contains the papers given at a symposium on gas chromatography organized by the Institute of Petroleum in May 1956. It includes the discussion and the recommendations made about nomenclature.

Nouveau traité de chimie minérale, edited by Paul Pascal. Vol. x: Azotophosphore. Pp. xxxix + 963. Masson et Cie, Paris. 1956. Paper covers; Fcs 6600; bound: Fcs 7500 net.

This is volume x—although only one other volume has so far been published—of what will ultimately be a very comprehensive nineteen-volume work on inorganic chemistry compiled under the distinguished editorship of Professor Paul Pascal. About two-thirds of the present volume is devoted to nitrogen—by Professor Pascal himself—and the remainder to phosphorus, by Professor René Dubrisay. As was indicated by the form of volume 1, the treatment is exhaustive; there is a mass of data and a most extensive bibliography. It is clear that when complete this work will become one of the standard works of chemical reference.

Biographical Memoirs of Fellows of the Royal Society, Vol. II. Pp. 345. The Royal Society, London. 1956. 30s. net.

This is the second of the new series of obituary notices of Fellows of the Royal Society. Following the pattern of the previous volume, it gives authoritative biographies of twenty-two Fellows who died in 1955–56. Each biography gives not only much personal detail and a critical appraisal of the subject's scientific work, but a list of all his publications.

Theories of the Universe, edited by M. K. Munitz. Pp. x + 437. The Free Press, Glencoe, Illinois. 1957. \$6.50 net.

The editor of this book seeks to present a history of cosmology, for the general reader, by means of a selection from the non-technical writings of those who have played a leading part in the development of the subject. Chronologically the span is very great, ranging from Aristotle, Plato, and other philosophers of classical antiquity to Einstein, Hubble, and other cosmologists still living.

Notes on contributors

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Was born in Monmouthshire in 1896. He entered University College, London, in 1920 and graduated in chemistry. Now Reader in the History of Science in the University of London. Has written extensively on the history of chemistry, including an authoritative book on Lavoisier's life and work.

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Was born in 1923 and was educated at the Cambridgeshire High School and St Catharine's College, Cambridge. He spent three years with the Iron and Steel Institute and the British Iron and Steel Research Association studying the fouling and corrosion of ships' hulls. In 1947 he returned to Cambridge and in

1949 joined the Agricultural Research Council's Unit of Animal Reproduction in Cambridge, where he first became interested in the physiology of mammalian spermatozoa and fertilization. During 1952-53 he spent a year's leave of absence at the University of Illinois, and in 1955 joined the staff of the Division of Experimental Biology of the National Institute for Medical Research.

C. R. AUSTIN,
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Was born in 1914 in Sydney, Australia, and was educated at Eastbourne College, England, and Sydney University. He was a member of the research staff of the Commonwealth Scientific and Industrial Research Organisation, Australia, from 1938 to 1954, investigating biochemical aspects of pregnancy toxæmia in sheep, the development of special operational and emergency rations for troops, and the physiology of reproduction. He joined the research staff of the Medical Research Council, England, in 1954. He is currently engaged in research on mammalian fertilization and associated phenomena. He has been a Secretary of the Society for Endocrinology since 1956.

L. F. BATES,
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Was born at Kingswood, Bristol, in 1897, and was educated at the Merchant Venturer's School and the University of Bristol. He served as a commissioned radiographer in India during the first world war, returning to carry out research at Bristol in 1920-22 and in the Cavendish Laboratory, Cambridge, 1922-24. In the latter year he joined the staff of University College, London, and was made Reader in

Physics in 1930. In 1936 he was appointed Lancashire-Spencer Professor of Physics at Nottingham, where he has been Deputy Vice-Chancellor of the University. His research school at Nottingham is distinguished for its contributions to experimental magnetism. He was President of the Association of University Teachers 1938-39 and President of the Physical Society 1950-52. His book 'Modern Magnetism' and his British Council publication on 'Sir Alfred Ewing' are well known.

P. W. BRIAN,
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Was born in Birmingham in 1910 and was educated at King Edward's School, Birmingham, and King's College, Cambridge. He worked at Long Ashton Research Station from 1934 until 1936, when he joined Imperial Chemical Industries Limited as a mycologist at Jealott's Hill Research Station. Since 1946 he has been Head of the Department of Microbiology at the Akers Research Laboratories. He has written numerous papers on the biological activity of fungal metabolic products.

JOHN FREDERICK GROVE,
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Was born at Sheffield in 1921. Studied at King's College, University of London, under A. J. Allmand. In 1941 he joined Imperial Chemical Industries Limited as a research chemist and was appointed Head of the Organic Chemistry Department of the Akers Research Laboratories in 1950. His publications are concerned mainly with chemicals for pest control, mould-product chemistry, and the application of physical methods to the study of problems in structural organic chemistry.

ENDEAVOUR

A quarterly review designed to record the
progress of the sciences in the service
of mankind

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Réaumur, a forgotten technologist

René-Antoine Ferchault de Réaumur was born on 28th February 1683 and died just two centuries ago, on 18th October 1757, after nearly fifty years of very active membership of the Paris Academy of Sciences. He was elected to the Academy at the early age of twenty-five; he contributed seventy-five original memoirs to its proceedings, almost equally divided between the physical and the biological sciences; he was director twelve times, on the first occasion when he was only thirty-one, and deputy-director nine times. The breadth of his knowledge so impressed those who knew him that he was described as 'the Pliny of the eighteenth century'. Despite this, the general public even in his own country are reminded of him only by a thermometer that bears his name—but has no resemblance to the instrument that he devised—and by a station on the Paris 'Métro'.

Réaumur first studied law but preferred mathematics and physics, and it was as a mathematician and 'pupil' of the geometer Varignon that he entered the Academy of Sciences. After submitting a few mathematical papers, he turned to natural history and to the useful arts, or what we now call technology. In natural history he made one discovery after another in a remarkable series of experiments and observations, which it is impossible to recall here even in the briefest terms. Mention must, however, be made of his great *Mémoires pour servir à l'histoire des insectes*, published in six quarto volumes in Paris from 1734 to 1742. This was a work of about 4000 pages with over 250 plates, carrying in all about 5000 illustrations. By this monumental study Réaumur became one of the founders of entomology. Publication was incomplete when he died and a seventh volume has recently appeared, two centuries after the sixth, while material for an eighth is available.

In 1711 Réaumur was promoted in the Academy to *pensionnaire mécanicien*: the *pensionnaire* indicates that he received a small salary and the *mécanicien* is perhaps best rendered in English as engineer or even as technologist. By this promotion his interest in the useful arts was recognized, and he was placed in charge of the Academy's projected compilation of a series of volumes on the various industries and trades. This was the famous *Descriptions des Arts et Métiers*, which appeared in 27 folio volumes from 1761 onwards, all after Réaumur's death.

His interest in technology was remarkable. He

reported to the Academy on the manufacture of mirrors, the working of slate, making artificial pearls, the gilding of leather, mining for iron, the drawing of gold wire, the properties of paper, alluvial gold in French rivers, and many other topics. In 1722 he made what is probably his most important contribution to technology in his *L'Art de convertir le Fer forgé en Acier*, etc., which has lately been translated into English. It is enough to emphasize here the experimental nature of Réaumur's researches on iron and steel: this work was essentially a technical research, and it was intended to encourage the practical application of the results that it announced. It led to the introduction into France of the manufacture of steel. For this important contribution to French industry Réaumur received from the Duke of Orléans, then Regent of France as Louis xv was still a minor, an annual pension of 12 000 livres. The terms of this grant were modified, at Réaumur's request, so that after his death the allowance might be perpetuated to the Academy for the further promotion of experimental studies on the improvement of the useful arts.

A few years previously, in 1715, Réaumur had reported to the Academy on the neglected turquoise-mines in Languedoc. He showed that the native gemstones were as good as those brought from Persia, and he carried out experiments that led him to conclude that the turquoise consisted of fossilized bones coloured by fusion with some metallic substance. This was a creditable conclusion in the light of the chemical knowledge of that time, and indeed one not without a germ of truth, for we now know this material to be a copper aluminium phosphate.

After his work on iron and steel, Réaumur's attention was turned in 1725 to the manufacture of another product that was imported into France from Germany, namely tinplate. Again he proceeded to experiment; as with steel, the product was known but the process of making it was kept secret, or at least as secret as trade-processes could be kept. Réaumur found that one of the important stages in the plating process was the removal of scale from the iron to give a clean surface for tinning. By experiment he discovered that vinegar was both the most satisfactory and the cheapest agent for this. Another industry was thus introduced into France.

In 1727-29 he made similar researches on

porcelain, comparing that from China and Japan with that produced in France and Germany. He noted that oriental porcelain had a solid compact texture, and that the European imitations of it were porous. He heated all three and found that, while that from China was unaffected, the French and the German products both vitrified. These results led him to conclude that European porcelain contained two vitrifiable substances, and that the Japanese product was made from one vitrifiable ingredient and another that was non-vitrifiable, the former on fusion enveloping the latter to give a semi-transparent product. This work was subsequently extended by his successors, more particularly by Macquer (ENDEAVOUR, 16, 133, 1957), a director of the Royal Porcelain Factory at Sèvres.

Besides these studies, Réaumur compiled a volume on the manufacture of anchors and another on the making of pins, as well as a new edition of the book on making cast iron malleable. He showed how to preserve eggs in a state of freshness for long periods: he found that it was necessary to seal the pores of the shell and that this could be done by means of a coating of varnish or grease. His classic studies on the artificial incubation of eggs appeared in a well-illustrated two-volume work in 1749 and in a later abridged edition, as well as in translations.

Enough has been said here to indicate Réaumur's deep interest and active concern in all practical applications of scientific knowledge and discovery, and in the improvement of the useful arts through a scientific understanding of the processes involved. All work of this kind that he embarked upon was inspired by the belief that the scientific and the useful were indissolubly connected.

This belief is revealed in a most striking manner in a memorandum ascribed to Réaumur and quoted by Maindron, the historian of the Academy of Sciences. Written between 1716 and 1727, this document emphasizes the services that the Academy could render to France if it were provided with such financial support as would, in Réaumur's view, prove trivial in comparison with the valuable results that would follow. The memorandum criticized the wisdom of relying for scientific progress on the spare-time studies and experiments of men engaged in other pursuits for the greatest part of every day. It pointed to the use-

fulness of astronomy in navigation, in cartography, and in the study of tides. It stressed the importance of mechanics in all matters related to machines, and the practical value of chemistry, botany, and anatomy were made equally clear. The importance of mechanics was particularly emphasized, and this science was ranked among those most useful to a nation. As for the *mécaniciens* themselves, Réaumur explained that those whom he had in mind were not the ordinary craftsmen with a knowledge of the motive powers and able to give an opinion about new machines that might be proposed; he was thinking rather of men thoroughly instructed in all the arts, aware of their defects and intent on their improvement, and eager to introduce into France suitable new industries that had already been successfully established in other countries. He proposed the creation of various salaried appointments, within their special fields of interest, for members of the Academy, so that their livelihood would be secured. He recommended that a collection of all native raw materials should be established and that a large laboratory should be set up for the use of the Academy, every member of which should have a special annual task allotted to him as one of his studies.

Réaumur was truly Baconian in seeing no limit to the useful things that might be discovered by such a reorganization and endowment. He was most modern in his fear of the perils of inflation, pointing out that the success of such a scheme would depend, not on the granting of sums of money that might be affected by various changes, but by such solid endowments in land as were possessed by the universities of Oxford and Cambridge. He considered that a single discovery might well repay the whole cost. He concluded the memorandum by saying that it was a mere sketch of the advantages that might be derived from the work of the Academy for the furtherance of the wealth and glory of France, as had been intended by Colbert when the Academy was first established. Written perhaps about 1720, the memorandum reveals the far-sighted vision of one who saw science almost with the eyes of Francis Bacon, but with far greater knowledge and understanding, and one who was among the first to realize that it is only from the finest theory that the finest practice is born.

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Nuclear magnetic resonance

R. E. RICHARDS

Nuclear resonance spectra in bulk matter were first observed in 1945. In the relatively short time that has since elapsed, nuclear resonance spectra have been used to solve an extraordinary range of problems in physics and chemistry: from the extremely accurate determination of nuclear moments to the estimation of moisture in solids, from the study of minute defects in crystal lattices to the elucidation of the structures of complicated organic molecules.

GENERAL PRINCIPLES

When atomic nuclei are placed in a constant magnetic field of high intensity and subjected at the same time to a radio-frequency alternating field, a transfer of energy takes place between the high-frequency field and the nucleus. This phenomenon is known as nuclear magnetic resonance. Spectra due to nuclear magnetic resonance result from many atomic nuclei having 'spin' angular momentum. This property of spin was first ascribed to the nucleus by Pauli in 1924 to account for certain aspects of atomic spectra, and nuclear spin has since become an important concept in the explanation of various other phenomena such as the existence of ortho and para states of certain molecules like hydrogen. Not until 1945, however, were nuclear magnetic resonance spectra observed in bulk material, and then almost simultaneously by E. M. Purcell, H. C. Torrey, and R. V. Pound [1], and by F. Bloch, W. W. Hansen, and M. E. Packard [2].

The idea of spin of the electron is now a familiar one. Just as we characterize the spin of the electron by a quantum number, $s = \frac{1}{2}$, so the spin angular momentum of a nucleus is characterized by another quantum number, usually symbolized as I . For nuclei, $I = n/2$, where n is zero or integral; for a given nucleus the value of n must be found experimentally.

Since the nucleus is positively charged, there is associated with its spin a circulation of electric charge. Just as the circulation of electric charge gives rise to a magnetic moment when a current flows through a coil of wire, so the circulation of charge associated with the spin of the nucleus causes it to possess a magnetic moment. The nucleus may therefore be regarded as a spinning particle with a weak magnetic moment directed along its axis of spin. This moment can be expressed as

$$g\beta[I(I+1)]^{1/2}$$

where β is a unit of magnetic moment called the

nuclear magneton, and g is the 'nuclear g factor' which must be found by experiment.

If a nucleus is placed in a uniform magnetic field, H_0 , it experiences a torque which tends to orient it so that its North-seeking pole points towards the North pole of the magnet generating the field, just as a compass needle is oriented by the Earth's magnetic field to point North and South. Unlike a compass needle, however, the nucleus does not assume the most stable orientation in the magnetic field more or less immediately, but precesses about the applied field. This motion arises from the interaction of the angular momentum of the nucleus with the torque exerted on it by the magnetic field; it is analogous to the precession of a gyroscope spinning in the Earth's gravitational field (figure 1).

The potential energy of the nuclear magnet in the magnetic field H_0 clearly depends on its orientation with respect to the field, because the torque exerted by the magnetic field always tries to turn the nucleus towards its most stable position, in which the component of the nuclear moment along H_0 is a maximum. The quantum theory requires that this energy shall be quantized in such a way that the component of magnetic moment in the direction of H_0 is $mg\beta$, where $m = I, I-1, I-2, \dots, 0, -1, -2, \dots, -I$. The potential energy of the nucleus in these levels can therefore be expressed as

$$U(m) = -H_0mg\beta \quad \dots (1)$$

Each energy level corresponds to a different orientation of the nuclear magnet with respect to the field H_0 . The number of allowed levels is clearly $2I+1$, and in each of these levels the nucleus precesses about the direction of H_0 , but maintains its correct orientation in the field. Figure 2 shows the possible energy levels in the magnetic field for the simple case of nuclei having spin quantum number $I = \frac{1}{2}$ and $I = 1$. The maximum allowed

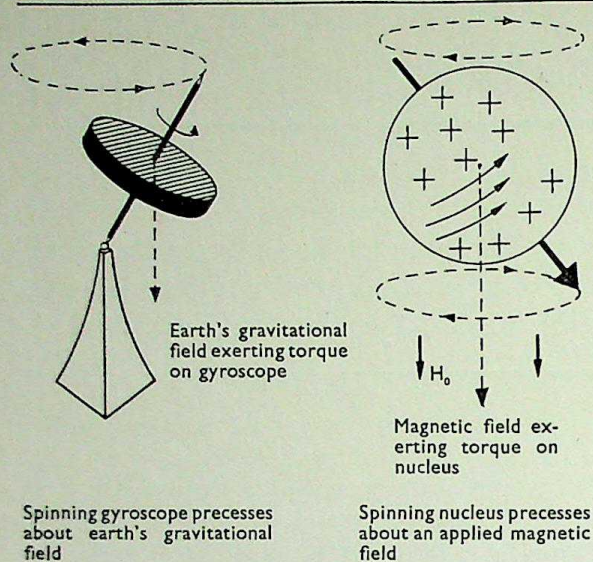


FIGURE 1 - Precession in gravitational and magnetic fields.

component of the magnetic moment along the field, when $m = I$, is $Ig\beta$, and it is this quantity which is usually referred to as 'the magnetic moment', μ , of the nucleus. From (1) it follows that the energy difference between two adjacent levels, m and $m + 1$, is given by

$$\Delta U(m \rightarrow m + 1) = U(m) - U(m + 1) = H_0 g \beta (m + 1 - m) = H_0 g \beta = \mu H_0 / I \dots (2)$$

If a system of nuclei in a magnetic field is exposed to radiation of frequency ν_0 , such that the energy of a quantum of the radiation, $h\nu_0$, is exactly equal to the energy difference between two adjacent nuclear energy levels ($H_0 g \beta$), then energy transitions may occur in which the nuclei are as it were flipped back and forth from one allowed orientation to another.

A quantum of energy is equally likely to tip a nucleus in either direction, so there is a net absorption of energy from the radiation only when the number of nuclei in one energy level exceeds the number in another. Such an excess would occur if the nuclei were in thermal equilibrium with their surroundings, and therefore populated their energy levels according to a Boltzmann distribution. In these circumstances a nuclear magnetic resonance spectrum is observed, the lines in the spectrum corresponding to the energies required to flip the nuclei among their allowed orientations in the magnetic field. Since the energy levels are equally spaced, only one line is observed, at a frequency corresponding to the constant difference, $g\beta H_0 = \mu H_0 / I$, between the energy levels.

The radiation required for these experiments

lies in the radio-frequency region. For example, for protons in a field of 10 000 gauss, radiation of frequency about 42.6 Mc/s is required. As there is a linear relation between the resonance frequency ν_0 and the magnetic field H_0 , nuclear magnetic resonance spectra can be expressed equally well as intensity of absorption plotted against frequency, at fixed field H_0 , or against magnetic field at fixed frequency ν_0 . One scale is readily converted to the other by the numerical factor relating H_0 and ν_0 .

MEASUREMENT OF NUCLEAR MOMENTS

The relationship between H_0 , ν_0 , and μ for a nucleus provides a method of measuring nuclear moments, and this was first used by I. I. Rabi and his colleagues [3] in studying nuclear resonance in the nuclei of atomic and molecular beams. The direct observation of such spectra in bulk matter provides an accurate method of measuring ν_0 in a given field H_0 , and extensive measurements of nuclear moments have been compiled [4]. The accuracy of the measurements is limited by the accuracy of the determination of the frequency at the centre of the line and of the magnetic field measurement. The accuracy of the frequency measurement is limited by the line width, which is extremely small in liquids; in solids, however, the lines are often broad and unsuitable for measurement. An important limitation is connected with the magnetic field at the nucleus; this is not identical with the applied magnetic field because of the influence of the extranuclear electrons. This effect can lead to errors in the measurement of nuclear moments ranging from a few parts per million to one part in a thousand, but the study of the effect itself in different molecules leads to other important inferences. The spectra are also often

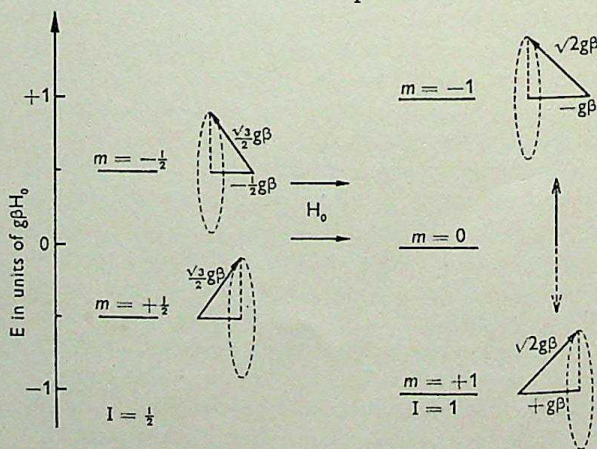


FIGURE 2 - Energy levels in magnetic field for nuclei having $I = \frac{1}{2}$ and $I = 1$.

complicated by interactions between the nuclei themselves, or between the nuclei and the molecular electrons, and we shall later consider how these interactions can yield useful information. Before doing so, however, something must be said of the general nature of the apparatus used.

APPARATUS

The apparatus for nuclear magnetic resonance experiments is relatively simple. A large magnet is required to provide the main field H_0 , and electronic equipment to generate the radio-frequency radiation and to measure its absorption by the sample. The radio-frequency equipment need not be very complicated, and its construction involves only well known principles of radio- and audio-frequency techniques. The magnet may be either electrically energized or a permanent magnet; each has special merits for particular applications. The magnetic field generally used is in the range 3000–12 000 gauss; it is an advantage to work at the highest field strength that can be obtained. For the study of broad lines, a small magnet with pole faces of about 13 cm diameter and a gap of about 5 cm is convenient. To measure the very sharp lines from liquids, the magnet must provide a field that is stable and homogeneous over the sample by an amount less than the line-width. For 'high resolution' measurements on liquids, this means that the homogeneity and stability of the field must be about 1 part in 10^8 , and this formidable specification can at present be met only by rather large and elaborate magnets.

STRUCTURE OF SOLIDS AND INTERNUCLEAR DISTANCES

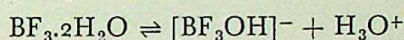
Because of its magnetic moment μ , a hydrogen nucleus ($I = \frac{1}{2}$) fixed rigidly in a crystal generates a weak local magnetic field H_{loc} . A second nucleus, near by, therefore experiences a total field ($H_0 \pm H_{loc}$), the sign depending on the particular orientation in the applied field adopted by the first nucleus. H_{loc} is proportional to μ/d^3 , where d is the internuclear distance, because the magnetic field generated at a distance D from a point dipole is proportional to μ/D^3 .

A solid containing pairs of hydrogen nuclei, such as a salt hydrate, will therefore give a proton resonance spectrum in the form of a doublet; the two components correspond to the two effective fields, ($H_0 + H_{loc}$) and ($H_0 - H_{loc}$), which any individual nucleus can experience through magnetic interaction with its neighbour.

It can be shown that triangular configurations

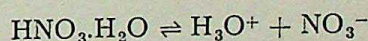
of nuclei in a solid give absorption curves with three peaks [5], and tetrahedral arrangements give absorption curves with rather flat tops [6]. The shape of the curve can therefore be used to identify the configuration of nuclei in simple cases; moreover, as the widths are proportional to $1/d^3$, the internuclear distances can also be measured. This method is particularly useful for studying hydrogen atoms, which are so difficult to locate accurately by other methods [7].

The use of the method may be illustrated by studies on boron trifluoride dihydrate [8]. In the liquid state this substance has been shown by Raman spectra and conductivity measurements to be ionized, to the extent of about 20 per cent, according to the equation



In the crystalline hydrate the structure must be either entirely non-ionized or completely ionic. In the former case a proton resonance would find expression in a broad doublet, due to the pairs of protons in the water molecules; in the latter case the proton resonance would be wider and have three maxima, of which the central one would be the more intense because of the narrow component of the relatively isolated hydrogen of the $[\text{BF}_3\text{OH}]^-$ ion. It was in fact found that slowly crystallized boron trifluoride dihydrate gives a doublet proton resonance at 90°K , showing that it has passed completely into the non-ionized condition.

This behaviour is in contrast with nitric acid monohydrate, which in the liquid state is ionized to about the same extent as boron trifluoride dihydrate:



When this substance is crystallized, it becomes completely ionic [9] and the proton resonance has three maxima.

With both $\text{BF}_3 \cdot 2\text{H}_2\text{O}$ and $\text{HNO}_3 \cdot \text{H}_2\text{O}$ it was found that rapid cooling of the liquid would produce a glass which showed proton resonance spectra consistent with the presence of both ionized and non-ionized molecules. If it is possible to grow large single-crystals, more can be learnt, such as the orientation of the molecules with respect to the crystal axes.

In crystals which contain more complicated groups of nuclei, the absorption lines usually coalesce to give one undefined curve. J. H. Van Vleck [10] has shown that the mean square width, or second moment, of the absorption curve is

related to the sum of the inverse sixth powers of the internuclear distances in the crystal. It is often possible to use this relationship to locate the hydrogen atoms in a crystal when the positions of the other atoms have been found by X-ray methods, or when there is a high degree of symmetry. Measurements of bond lengths to hydrogen have been made by this method on the ions NH_4^+ [6], PH_4^+ [11], BH_4^- [12], and NH_2^- [13]. The hydrogen atom has been located in the hydrogen bonds formed in the HF_2^- ion and in hydrazine fluoride. In the former [14] the hydrogen atom is found to be centrally placed between the two fluorine atoms; in the latter, however, the N-H distance is 1.075 Å, while the H-F distance is 1.542 Å [15].

When resonances of nuclei for which $I > \frac{1}{2}$ are studied, the width of the line may be determined by another interaction much more potent than that considered above. Nuclei with spin quantum numbers greater than one-half usually possess an electric quadrupole moment as well as a magnetic dipole moment. The electric quadrupole moment arises from aspherical distribution of the positive charge over the nucleus; the charge may be distributed over a prolate or an oblate ellipsoid, and which of these obtains determines the sign of the electric quadrupole moment.

In a uniform electric field the magnitude of the quadrupole moment is independent of its orientation, but if the electric field has a gradient—which might arise, for example, from an unsymmetrical arrangement of other atoms in the molecule—then the energy of the nucleus will be lower in certain orientations than in others. For example, a nucleus with a sausage-shaped distribution of positive charge will prefer to orient itself in the region of lowest positive potential in a non-uniform electric field. The energy of the nucleus due to its angular orientation has the form:

$$\text{Quadrupole moment} \times \text{field gradient} \\ \times [3m^2 - I(I+1)]$$

and has to be added to or subtracted from the magnetic energy levels according to the sign of the term $[3m^2 - I(I+1)]$. Some of the magnetic energy levels are therefore raised and some lowered, since $m = I, I-1, \dots, 0, -1, \dots, -I$. This is illustrated in figure 3, which relates to a nucleus for which $I = 3/2$. The levels for which $m = \pm 3/2$ are raised in energy by the electric quadrupole interaction, and those for which $m = \pm 1/2$ are lowered in energy. The nuclear energy levels characterized by the different values of m are now no longer equally spaced, and instead of one

observed absorption line there are several—in this case three. From measurement of the separation between the nuclear resonance lines this quadrupole interaction can be calculated, as a product of the electric field gradient at the nucleus and the nuclear electric quadrupole moment. If one of these parameters is known, the other can be evaluated. Unfortunately nuclear quadrupole moments are not very accurately known, but in some cases measurements of these effects in single-crystals can give extremely detailed information about the crystal structure [16, 17].

The quadrupole interaction energy is zero in perfect cubic crystals because there is no electric-field gradient at the nucleus. Small imperfections in the crystals, or even mechanical strains, can destroy this electric field symmetry, and the broadening or splitting of the nuclear resonance lines can provide an extremely sensitive measure of such an effect [16].

MOLECULAR MOTION IN SOLIDS

The widths and shapes of the absorption lines in the nuclear magnetic resonance spectra of solids are often found to depend on temperature; the absorption lines become narrower rather suddenly as the temperature is raised. The local magnetic fields generated by neighbouring nuclei are evidently being reduced as the temperature is raised. The usual mechanism by which this is effected is molecular motion in the solid, which more or less evens out the interactions. The molecular motion usually consists in hindered reorientation among a number of stable positions, and from the shape and width of the line at high temperatures the nature

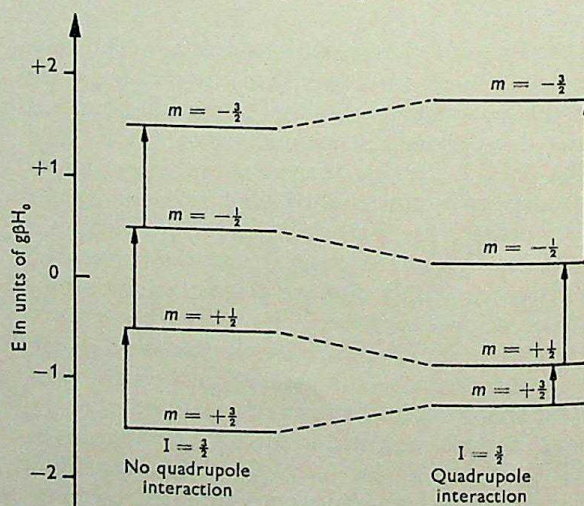


FIGURE 3—Energy of nucleus in non-uniform electric field, with and without quadrupole interaction.

of the motion can be discovered. For example, it has been shown [18] that at 93° K the CH_3 group of acetonitrile undergoes hindered motion in the solid about the C-C axis, and that in hydrazine sulphate the $\text{N}_2\text{H}_6^{++}$ ion reorients itself about the N-N axis at room temperature [19]. Motion taking place during self-diffusion can also bring about narrowing of nuclear resonance lines.

Further information about molecular motion can be derived from a study of the so-called 'spin lattice relaxation time', T_1 , of the nuclei. This defines the time required for a nucleus to exchange a quantum of energy with its immediate surroundings. A nucleus having spin quantum number $I = \frac{1}{2}$, occupying one of its allowed energy levels in a magnetic field, enters into no interaction that can change its orientation within the molecule or crystal in which it is situated, except that resulting from its own magnetic moment. Its energy level, or orientation, can therefore be changed only by the influence of a magnetic field oscillating at a frequency near the resonance frequency. It has been shown that the coefficient of spontaneous emission by a nucleus in an upper energy level is quite minute, but it is found experimentally that the lifetimes of nuclei in a given level vary enormously, from times of the order of 10^{-4} seconds to many hours; these lifetimes are expressed in terms of T_1 . If the molecules in a solid are jumping back and forth among a number of allowed rotational positions, then the local fields generated by the nuclei of a molecule, and experienced also by neighbouring nuclei, will fluctuate in intensity. There will usually be a range of frequencies of field fluctuations, with a maximum at some particular frequency. The component of this range of frequencies that is near the resonance frequency of neighbouring nuclei will be able to induce transitions in them; energy can thus be exchanged between the nuclear magnetic energy levels and the molecular motion. This process is the more effective the more intense are the local field fluctuations near the resonant frequency.

The vibrational frequency at which molecular reorientation occurs in a solid usually rises with temperature, so that the region of maximum intensity of the local field fluctuations also rises in frequency as the temperature is raised. Thus the relaxation of the nuclei by this mechanism is most effective when the temperature of the crystal is such that the maximum intensity of the local field fluctuations corresponds to the resonance frequency of the nuclei; under these conditions, a short relaxation time, T_1 , is observed. If the temperature is

lowered from this point, the local field fluctuations slow down and their maximum intensity shifts to lower frequencies, away from the resonance frequency. Relaxation of the nuclei becomes less effective, and in consequence T_1 rises. Similarly, at higher temperatures the maximum intensity in the spectrum of local field-fluctuations due to molecular motion shifts to frequencies higher than the resonance frequency, relaxation again becomes less effective, and again T_1 rises. A graph of T_1 against temperature for these solids therefore shows a minimum T_1 at a temperature at which the spectrum of frequencies of molecular motion is distributed with maximum intensity near the nuclear resonance frequency.

A study of the variation of T_1 with temperature therefore permits a calculation of the way in which the frequency of molecular motion varies with temperature. If the molecular motion is assumed to be hindered by a potential barrier of height V_0 , it would be expected that the number of molecules able to surmount the barrier would be proportional to $\exp(-V_0/RT)$, and so from the variation of frequency of reorientation with temperature it is possible to calculate the height of the barrier hindering the motion. It has been shown [20], from the observed change in T_1 with temperature, that in crystalline benzene the molecules undergo hindered reorientation about their hexad axes. The frequency of reorientation of the molecules varies logarithmically with temperature from $10^4/\text{sec}$ at 85° K to about $10^{11}/\text{sec}$ near the melting point, corresponding to a potential barrier of 3.7 ± 0.2 kcal/mole.

Self-diffusion also provides a mechanism for narrowing the absorption line and reducing T_1 . Its effect in solid cyclohexane is significant [21]; in the alkali metals [22] large changes in line-width with temperature can be interpreted in this way.

LINE WIDTHS IN LIQUIDS

When a solid is melted or dissolved in a solvent, the molecular motion in the liquid is so vigorous as to even out completely all the broadening interactions so far discussed, and very narrow absorption lines may be obtained. Line-widths in liquids vary from about 10^{-4} gauss to many gauss, depending on circumstances.

A system containing a liquid and a solid phase will give a nuclear resonance spectrum which is a superposition of a narrow and a broad line. It is particularly easy to measure the intensity of the narrow component of the spectrum, which is due to the liquid, and this is a measure of the number

of nuclei in the liquid phase. It is therefore easy to estimate quantitatively the liquid component of a solid-liquid mixture, such as the content of moisture in materials.

Since the local magnetic fields generated by the nuclei are averaged to zero by the random molecular motion in liquids, these cannot contribute to the line-width, which is now dominated by relaxation processes. If T_1 is regarded as a measure of the lifetime of a nucleus in a given energy level, then the Heisenberg uncertainty principle predicts a broadening of the energy level approximately in accordance with the equation

$$\Delta E \times T_1 = h\Delta\nu \times T_1 \simeq h/2\pi$$

This equation is not strictly accurate because the energy level is also broadened by other factors, but it gives the correct order of magnitude. In most organic liquids the value of T_1 for the protons is a few seconds, so that line-widths equivalent to about 2×10^{-4} gauss are observed. In viscous liquids, such as glycerine, the spectrum of local magnetic-field fluctuations due to the Brownian motion of the nuclei in the molecules has its region of maximum intensity at higher frequencies than in mobile liquids; the components of the spectrum near the nuclear resonance frequency are more intense for viscous liquids than for mobile liquids. It is therefore found that viscous liquids have short nuclear relaxation times and the proton resonance lines are correspondingly broadened. If the nucleus possesses an electric quadrupole moment, the nuclear relaxation time may be very short. If an atom in a molecule experiences at its nucleus an electric-field gradient resulting from the arrangement of the other atoms about it, this can produce strong electric quadrupole coupling with the nucleus of the central atom. As the molecule tumbles over in the liquid, the quadrupole interaction drags the nucleus over with the molecule and re-orientates it in the magnetic field in another allowed position. This effect can very greatly shorten the relaxation time and lead to broad nuclear resonance lines. When a change occurs in the molecule that increases the symmetry of the environment of the nucleus, the quadrupole interaction is reduced, T_1 becomes longer and the nuclear resonance line narrower. For example, the chlorine resonance line of the symmetrical ClO_4^- ion in aqueous solution is much narrower than the chlorine resonance line of the ClO_3^- ion [23]. This phenomenon has not yet been investigated extensively, but it promises to be a useful method of studying the structures of liquids and solutions.

CHEMICAL SHIFTS

The frequency at which a nuclear resonance line occurs is governed by the equation $h\nu_0 = \mu H_0/I$. Here H_0 is the magnetic field actually experienced by the nucleus, and, as has been indicated, this is not quite identical with the field applied to the sample by the magnet (H_{appl}). Two factors modify the applied field to give the resultant field H_0 ; both are effects induced in the molecular electron clouds by the applied magnetic field. They are therefore proportional to the applied field, and

$$H_0 = H_{\text{appl}}(1 - a + b)$$

The first term, a , is negative, and arises from the diamagnetism which is induced by H_{appl} in the molecular electrons. It is a property of all bulk matter that when it is placed in a magnetic field, circulating currents are induced in the electron clouds and generate a weak magnetic moment to oppose the applied field. This effect therefore reduces the magnetic field at the nucleus, and it is for this reason that we assign to a a negative sign. The second effect induced by the magnetic field is quantum-mechanical in origin; it can be regarded as a weak uncoupling of the valence electrons, which are normally perfectly paired. When the electrons are paired, their spins are opposed and in consequence the magnetic moments associated with them cancel one another. The applied magnetic field induces a slight deviation from this perfect pairing of the electron spins. A resultant paramagnetic moment is induced, which increases the effective field at the nucleus, so we assign a positive sign to b , which is often called the 'temperature-independent paramagnetism'. Both effects are induced by the field and proportional to it, and it is unfortunately not possible to separate them experimentally. Their combined effect may be written

$$H_0 = H_{\text{appl}}(1 - a + b) = H_{\text{appl}}(1 - c)$$

and it is found experimentally that the fraction c varies critically with the particular electron distribution or chemical environment of the nucleus.

It therefore follows from the above that, in a given applied magnetic field, the nuclear resonance line will occur at a frequency which varies with c and hence with the chemical environment of the nucleus. Alcohol, for example, shows three proton resonance lines having intensities in the ratio 3 : 2 : 1. The three lines arise from the protons in the methyl, methylene, and hydroxyl groups respectively; their intensities are proportional to the number of protons in each group. The characteristic positions of the resonance lines are referred

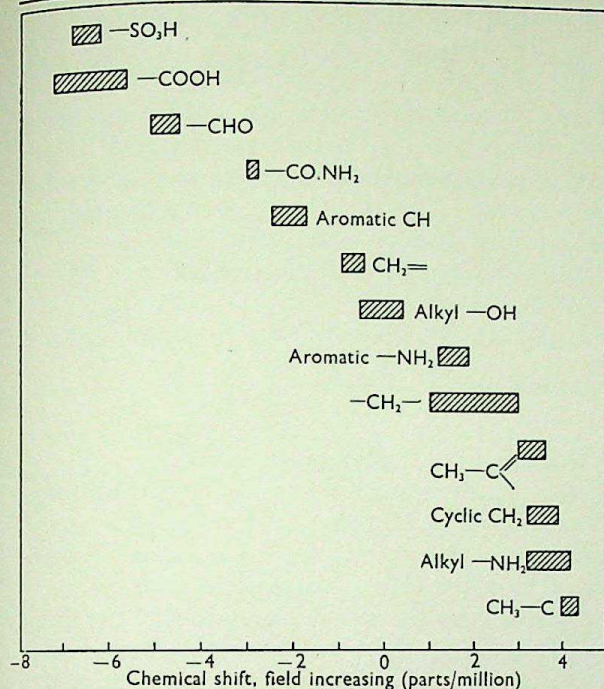
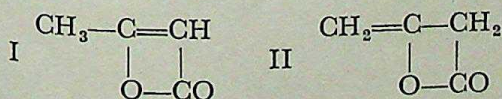


FIGURE 4 - Chemical shifts in relation to functional groups.

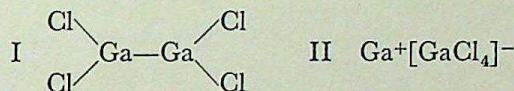
to in terms of 'chemical shifts', which are usually expressed as a fraction of the field by which the resonance is shifted from some arbitrary standard. The chemical shifts of proton resonance lines can be related to the functional groups in which the protons occur; figure 4 shows a few examples [24]. From the nuclear magnetic resonance spectrum of an unknown substance certain groupings can be identified, and often their relative numbers can be determined from the relative intensities of the lines. For protons the shifts are of the order of a few parts per million, but for other nuclei the effect may be much greater; cobalt compounds, for example, show shifts of the order of 1 per cent. The relation between shifts and chemical environment provides a very powerful method of studying molecular structure, and this is being especially exploited in organic chemistry.

An investigation of diketene, for example, illustrates the possibilities of the method. The structure of this substance has been studied by a wide range of chemical and physical methods, and two formulations could explain the experimental observations:



Structure I would give two proton resonance lines; one of intensity 3 from the CH_3 group, and one of

intensity 1 from the CH group. Structure II would give two lines of equal intensity from each of the two CH_2 groups. A drop of liquid diketene in fact showed two proton resonance lines of equal intensity in positions consistent with structure II, which is thus unambiguously identified [25]. Allinger [26] has recently measured the nuclear magnetic resonance spectrum of helvolic acid and some of its derivatives. Although this is a complicated organic compound having 32 carbon atoms, the spectrum provided crucial information which led to the final elucidation of the structure. Chemical shifts can be studied in many other nuclei and used for structural diagnosis and analysis. R. Freeman and R. E. Richards [27] have studied the gallium resonance in gallium dichloride. This substance is dimeric and diamagnetic, and could be formulated in two ways:



The liquid shows two gallium resonance lines, showing that it contains two different kinds of gallium atom and confirming Raman spectroscopic measurements which have been interpreted in terms of structure II [28].

MULTIPLY INTERACTION

Under higher resolving power the three main proton resonance lines of ethyl alcohol (from the methyl, methylene, and hydroxyl groups respectively) show fine structure (figure 5). This arises from a weak interaction and provides still further valuable information. The simplest molecule in which this so-called 'multiplet interaction' can occur is HD. The proton has a spin quantum number $I = \frac{1}{2}$, and for the deuteron $I = 1$; thus the proton can adopt two permitted orientations in the magnetic field and the deuteron three orientations. In the discussion of chemical shifts it was explained that a magnetic field can induce a weak uncoupling of valence electrons and produce a weak paramagnetism in them. The applied field, H_{app} , induces this temperature-independent paramagnetism uniformly over the molecule, but the local field of the proton produces an additional effect in the bonding electrons, which modifies very slightly the field experienced by the deuteron. This additional effect depends on which of the two possible orientations the hydrogen nucleus adopts; the deuterons find themselves in one of two different fields, and consequently the deuteron resonance is a doublet. Similarly, the protons

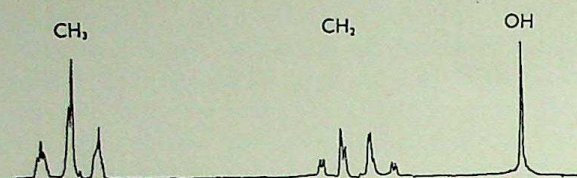
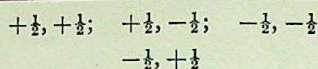
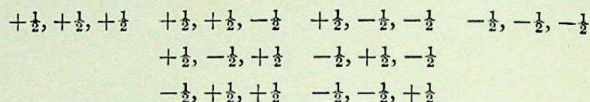


FIGURE 5 - Proton resonance spectrum of ethyl alcohol at 30 Mc/s, showing fine structure arising from second-order interaction.

experience a field that is modified by the additional paramagnetism induced in the bonding electrons by the deuteron. This induced field has three values, corresponding to the three orientations which the deuteron can adopt; consequently the proton resonance line is a triplet. The multiplicity of the resonance line of a nucleus or group of nuclei therefore reflects the number of orientations which the nuclei adjacent to it can assume. For example, in alcohol the methyl group is adjacent to the methylene group, which has two protons, each of which can have one of two orientations. The three different combinations of the methylene protons which the methyl group might 'see' are therefore



There are thus three lines, the middle one being twice as intense as the outer ones because there are two ways of arranging the methylene proton spins in this case. The methylene group experiences fields corresponding to the four possible ways of arranging the spins of the methyl group:



The intensities are this time in the ratio 1 : 3 : 3 : 1. Thus not only can the presence of particular functional groups be identified in a molecule from the positions of the chemically shifted nuclear magnetic resonance lines, and their relative numbers measured from the relative intensities of the lines, but from the multiplet structures it is often possible to decide the relative positions of groups in the molecule. It is easy to see why this powerful tool has been received with such enthusiasm by many organic chemists.

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Electrolytes in plant tissue

R. N. ROBERTSON

The absorption of electrolytes by plant tissue has been the subject of much research, not only because of its importance in the mineral nutrition of plants but also because its mechanism is not obviously explained by simple chemical concepts. The principal interest, from the latter point of view, is the capacity of plant cells to accumulate salts against a concentration gradient and their ability to discriminate between different, though similar, ions.

The simple picture of the plant cell shows a non-living, freely permeable cellulose wall surrounding the living part of the cell, the cytoplasm, which itself surrounds the non-living vacuole containing substances in solution with very little colloidal material. The cytoplasm is known to consist of a matrix or gel in which are embedded microscopically recognizable bodies. These bodies include a nucleus, plastids which in green cells contain chlorophyll, and mitochondria (figure 4). With the electron microscope smaller bodies termed microsomes are sometimes distinguishable, but these may possibly be derived from a rearrangement during fixation of an endoplasmic reticulum [11]. Somehow this cellular structure builds up an internal concentration of dissolved material, absorbs ions against the concentration gradient, and retains them in the cell. For example, a gram of carrot tissue will absorb almost all the salt from 17 ml of 0.005 M KCl in about 48 hours. During this time the concentration of KCl in the tissue rises to about 17 times the original external concentration and about 1000 times the final external concentration. Clearly, knowledge of the structure of the cell is essential to understanding how energy is expended for the absorption of the salt against a concentration gradient and how the absorbed salt is retained in the cell.

Early research on the absorption of non-electrolytes, particularly by E. Overton [20], suggested that substances which were more soluble in oils than in water were absorbed more readily than substances of similar molecular weight but relatively less soluble in oil. This led to the idea that living cells were surrounded by a membrane through which soluble substances would pass more readily if they were lipophilic or hydrophobic, an idea developed in great detail by R. Collander [5], J. F. Danielli [7], and others. Evidence based on the behaviour of a variety of cells suggested that the membranes consisted of orien-

tated lipid molecules, and though probably only two or three molecules in thickness offered resistance to the passage of hydrophilic molecules and ions. The plant cell seemed no exception to the general rule that entry of non-electrolytes was controlled by some such membrane. Though the observations did not indicate which part of the cell was being penetrated by the dissolved substances, it was assumed, on inadequate evidence, that the membrane was at the surface of the cytoplasm adjacent to the cellulose wall. A membrane of similar structure, and hence offering high resistance to the movement of hydrophilic substances, might, however, occur at the interface between the cytoplasm and the vacuole. For the last ten or fifteen years many plant physiologists have believed in the existence of a highly resistant membrane at the outer surface of the cytoplasm and of another at the surface of the vacuole. Some workers, e.g. W. H. Arisz and G. E. Briggs, have never accepted the suggestion of a membrane of high resistance outside the cytoplasm, and recently evidence has been accumulating that there is no such membrane.

For some years plant physiologists at Cambridge have regarded the surface of the cytoplasm as having water-filled spaces continuous with the water-filled spaces of the cell wall and the intercellular space systems. In 1948 G. E. Briggs and R. N. Robertson [2] pointed out that the diffusion of salts and larger molecules through carrot tissue was restricted to the regions outside the vacuoles but not necessarily outside the cytoplasm. Indeed, the nature of the potential difference when salt is diffusing from one side of a carrot slice to another suggested that diffusion was taking place in tissue which contained a large number of non-mobile anions, such as would occur in either cytoplasm or wall. The portion of a cell or tissue into which the solute from an external solution can penetrate readily became known in Cambridge as the 'free space'.

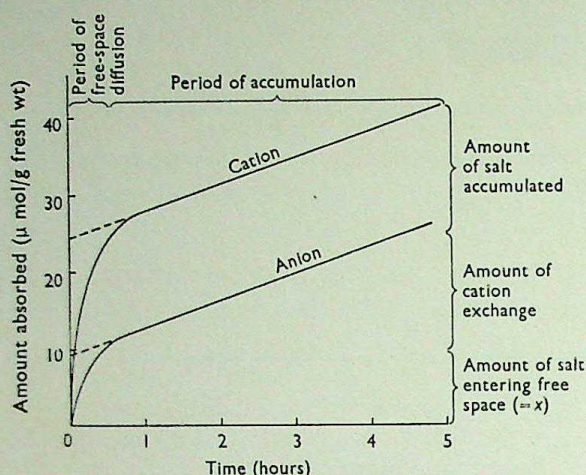


FIGURE 1 - Diagram showing the variation with time of free-space diffusion, cation exchange, and accumulation.

The concept of free space implies that the wall and cytoplasm of the cell allow free diffusion between the aqueous phases of the cytoplasm and the external solution (figure 1). The common observation that, when supplied externally, some intermediates of metabolism penetrate readily to the site of the reaction with which they are concerned is consistent with this view. Plant tissues will, for instance, respond readily to external application of acids of the Krebs cycle, indicating that these move rapidly into the cytoplasm. Since this space cannot be measured unless its properties relative to the method of measurement are defined, the concept of 'apparent free space' was introduced. Apparent free space was mentioned for the first time in publication by A. B. Hope and P. C. Stevens [14], with acknowledgment to Briggs, and in the last few years has been used by various investigators in the interpretation of their results [4, 15, 13, 9]. A discussion of apparent free space in relation to the physiology of the plant cell has been given by Briggs and Robertson [3] and a more detailed discussion by Briggs [1].

Apparent free space can be measured in various ways, but for present purposes it is sufficient to define it. If X is the estimated amount of solute (non-electrolyte or ion) taken up by the free space of cell or tissue from a solution of concentration C , then the apparent free space is X/C . In other words, the apparent free space is the volume by which the free space of the tissue appears to dilute the solution applied.

When electrolytes are used as the solute to measure the apparent free space, the free space behaves as though it contains non-mobile anions

balanced by mobile, mostly metallic, cations. From Donnan equilibrium considerations the non-mobile anions would be expected to exclude mobile anions, and so the entry of anions from the external solution would be restricted. On the other hand, since the cations of the external solution may exchange for the cations of the free space, the uptake of cations will frequently be greatly in excess of that of anions. If we were dealing with a simple Donnan system, the concentrations of the two ions would be given by the following equations:

$$[\text{Cl}^-]_i = \frac{1}{2} \sqrt{(a^2 + 4C_a^2)} - \frac{1}{2}a$$

$$[\text{K}^+]_i = \frac{1}{2} \sqrt{(a^2 + 4C_a^2)} + \frac{1}{2}a$$

where $[\text{Cl}^-]_i$ and $[\text{K}^+]_i$ are the internal concentrations of mobile anions and cations respectively, C_a is the external concentration of salt (assumed constant), and a is the concentration of non-mobile anions. The relationship of external to internal concentration would then be as shown in figure 2. In the plant cell, the free space contains a number of different non-mobile and mobile ions, but mobile cations, which can exchange with the cations of a salt applied externally, are always in excess of mobile anions. Such a difference between anion and cation absorption by the free space leads to the usual uptake relationship shown in figure 1. Thus if cation entry is used to estimate the apparent free space, high values are obtained compared with those based on anion uptake.

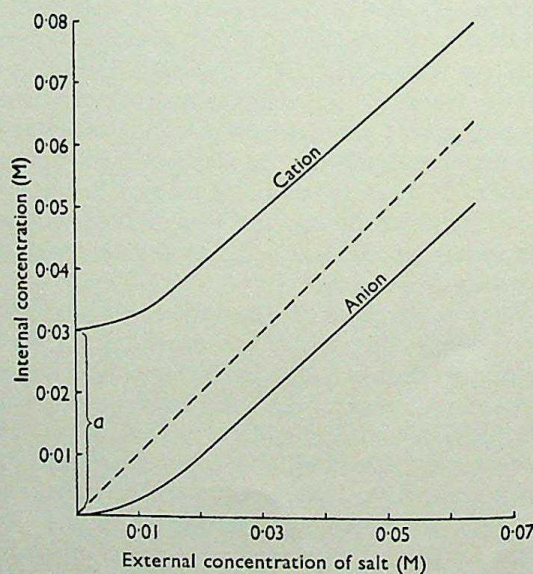


FIGURE 2 - Graph showing the equilibrium concentration of mobile cations and anions in a phase containing non-mobile anions (a) plotted against the concentration of salt in the external solution.

The surface of the plant cell consists of a cation-exchanging gel, similar to a cation-exchanging resin, which permeates both cell wall and cytoplasm, and realization of this allows various consequences to be discussed. The properties of the system depend on the concentration of the non-mobile anions (a), but estimation of this concentration is difficult. Early attempts to estimate the concentration from changes in the potential differences across cells or tissues with changes of salt concentration are too low by about an order of magnitude, through neglect of the divalent ions in cytoplasm and wall. A second method is to estimate the ratio of inside to outside concentrations of a particular ion: since divalent ions are more effective than monovalent ones in exchanging with ions already present, the ratios should be based on results with divalent cations. Calculations [3] from the data of W. Stiles and A. D. Skelding [24] suggest that the value of a may be as high as 0.4–0.6M.

There are many aspects of the concept of free space in cell wall and cytoplasm which cannot be discussed here, but the important idea is of the cytoplasm as a gel with structural rigidity due to the micelles of cytoplasmic protein. Non-mobile anions are part of this structural framework, which is rich in mobile cations and poor in mobile anions. While this system is adjusting itself to the addition of a salt, the process of accumulation begins.

'Accumulation', the term given to the results of 'active transport' against the concentration gradient, does not resemble the physical adjustment between cytoplasm and external solution just discussed. Though the process starts early in the physical adjustment between cell, cytoplasm, and external solution, accumulation continues for hours with very little change in rate, even though the internal concentration is increasing compared with the external. In dilute solutions the rate of accumulation increases with increasing external concentration, but it becomes independent of concentration in more concentrated solutions (figure 3). The rate of accumulation increases with temperature, the temperature coefficient suggesting that it depends on a chemical process. Since this process is dependent on expenditure of energy by the cell, any proposed mechanism must be related to respiration by which the cell derives its energy. Attempts to relate the process to respiration have led to a better understanding of what is involved but not, up to the present, to a proven explanation.

It was early shown that the respiration of certain tissues which had been washed for some time

in water could be increased by the addition of salt; in carrot tissue, for instance, the rate of oxygen uptake increases by 70 to 100 per cent after the addition of 0.01M KCl. This increased respiration was originally called anion respiration by H. Lundegårdh and H. Burström [19], but the term 'salt respiration' is probably more appropriate. Conditions which vary the rate of this salt respiration proportionately vary the rate of accumulation. Inhibitors, such as cyanide, which stop the salt respiration without at the same time inhibiting the basal or ground respiration in water, completely inhibit the accumulation. The fact that this salt respiration is inhibited by carbon monoxide in the dark, but not by carbon monoxide in the light, shows that it is catalysed by cytochrome oxidase. The energy for the process appears therefore to depend on that part of the respiration system which is normally controlled by cytochrome oxidase.

While energy is necessary for continued accumulation against the concentration gradient, the same mechanism does not seem to be necessary to maintain the concentration once it has been built up. Thus, when the cytochrome oxidase is inhibited by carbon monoxide or cyanide, the salt which has been accumulated does not leak out to the exterior. This implies that the salt which has been accumulated has been transported to some region of the cell from which it cannot escape quickly. In plants like *Nitella*, which have unusually large cells, it is possible to remove the sap from the vacuole with a minimum of contamination by the cytoplasm. Analyses of this sap show

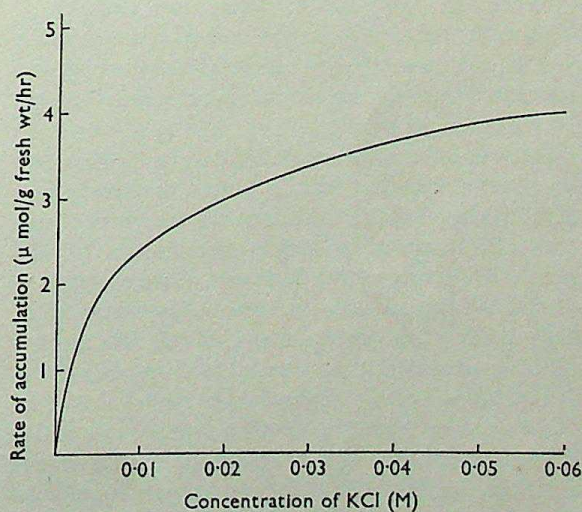


FIGURE 3 - Graph showing the relation between rate of accumulation by sliced carrot tissue and concentration in the external solution [23].

that accumulation has resulted in the salt concentration being increased within the vacuole: this suggests that energy is necessary to transport salt across the cytoplasm and through the membrane of high resistance which surrounds the vacuole. In ordinary plant tissue the cells are too small to permit easy analysis of the vacuole, as distinct from the cytoplasm, but indirect evidence from measurement of the impedance of these cells and of the increase in osmotic pressure following accumulation suggests that they too accumulate salt in the vacuoles.

Some years ago, Lundegårdh [17], impressed with the fact that the accumulation mechanism was dependent on a cytochrome type of respiration and that cations could exchange readily in plant cells, suggested that the mechanism might be an anion-carrier system depending directly on the cytochrome. His suggestion, in its simplest form, was that the cytochrome system, which carries electrons from the substrates of the respiration system to molecular oxygen at the surface of the cell, might function as a carrier of anions towards the centre of the cell, i.e. that unit negative charge in the form of an anion is carried in the opposite direction to unit negative charge in the form of an electron. If this were the mechanism, the maximum rate of accumulation would occur when one anion is transported into the cell for each electron transported to molecular oxygen. Lundegårdh thought that the hydrogen ions liberated from the substrate simultaneously with the electron passing to the cytochrome system would exchange for the cations in the external solution. In 1948 R. N. Robertson and M. J. Wilkins [22] showed that the rate of accumulation of salts approximated to, and did not exceed, the calculated rate at which electrons move through the cytochrome system.

Since Lundegårdh made his original suggestion we have acquired a much better understanding of the intracellular location of the enzymes which would be involved in such a mechanism. Lundegårdh originally thought that a membrane of orientated lipid molecules probably occurred on the outside of the cytoplasm and that the mechanism of accumulation was located in this membrane. Since then, however, he agrees [18] that the evidence from the concept of apparent free space implies that the cytoplasm is in continuous aqueous contact with the external medium. [Further, we now know that the cytochrome system in plant, as in animal, cells is associated with the mitochondria, bodies of about 1μ diameter occur-

ring in the cytoplasm. If, therefore, the accumulation mechanism is closely associated with the cytochrome system, whether by the mechanism suggested by Lundegårdh or by some other, the activity should be demonstrable in the mitochondria, the reactions and physical properties of which can be studied after removal from the cell.

Since mitochondria are so near the limit of resolution of the light microscope, the examination of their internal structure has been possible only since section-cutting techniques became available for the electron microscope. In a study of the structure of plant mitochondria [10] it has been shown that mitochondria fixed in intact beet tissue and there sectioned show a double membrane round the outside, approximately $170\text{ \AA}$ in thickness (figure 5). Internally not very much structure is apparent; some projections of the internal wall are similar to the cristae in animal mitochondria described by G. E. Palade [21] and others.

When the mitochondria are extracted from the tissue and then fixed, embedded, and sectioned ready for the electron microscope, some of the structure is lost, perhaps due to some swelling during extraction, but the membrane remains. R. N. Robertson, M. J. Wilkins, A. B. Hope, and L. Nestel [23] and S. I. Honda and R. N. Robertson [12] analysed extracted mitochondria, and showed that they constitute a Donnan system in which the mobile ions sodium, potassium, and (unless the mitochondria are extracted in the presence of a chelating agent) calcium, balance some non-mobile anions in the particle. If the mobile anion in the external solution is chloride, its concentration in the mitochondria is higher than would be expected on a Donnan adjustment, and often higher than in the external solution; this suggests that the mitochondria can accumulate.

The changes in internal concentration with time after a change in external concentration can be used to determine the diffusion constant of the salt in the membrane by applying Fick's law. From the half-times of adjustment, the diffusion constant of KCl in the mitochondrial membrane is calculated to be $1 \times 10^{-13}\text{ cm}^2/\text{sec}$. This means that the membrane on the outer surface of the extracted mitochondrion is about 10^8 times more resistant to the diffusion of KCl than is the same thickness of water. While it is at present impossible to say definitely that most of the resistance to diffusion in the mitochondrion is located in the

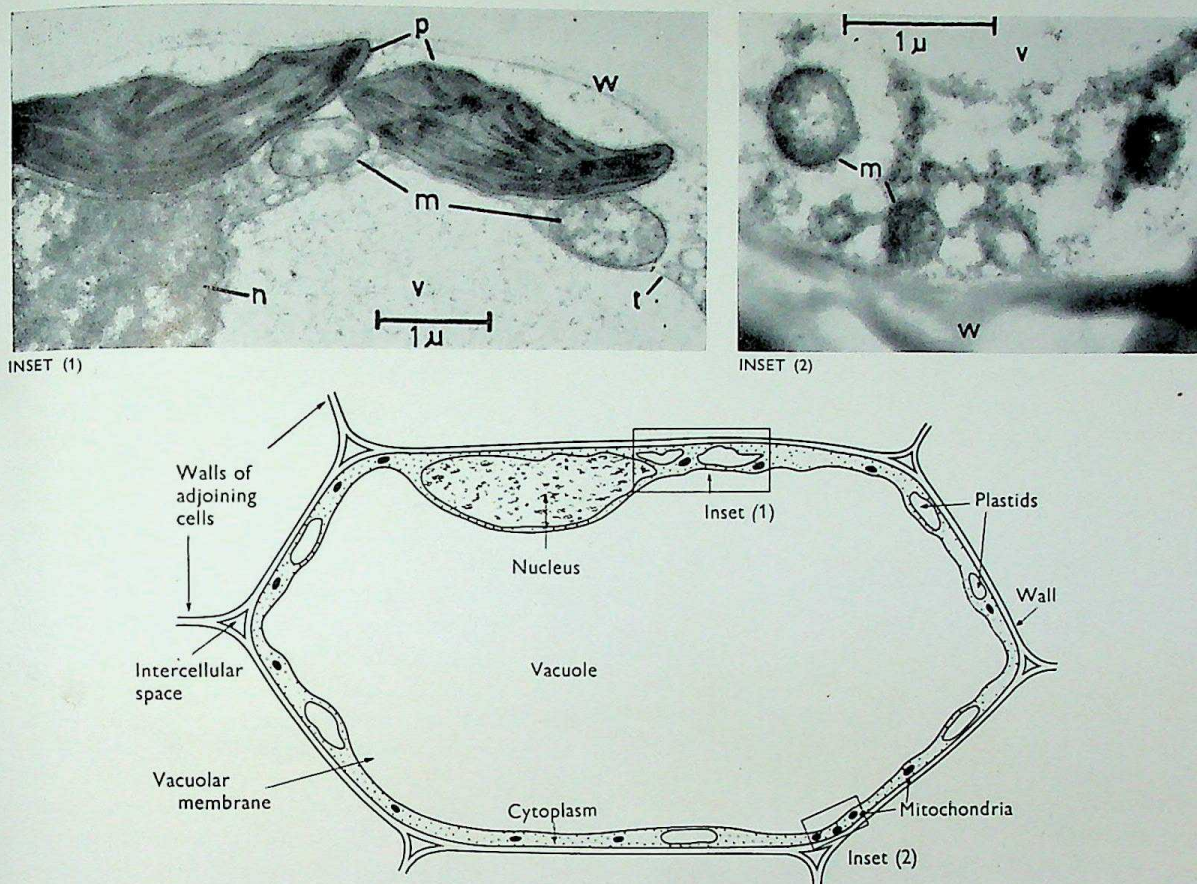


FIGURE 4 - A diagrammatic representation of the plant cell. The inset electron micrographs show (1) portion of the nucleus, plastids, mitochondria, and membrane against the vacuole (unpublished micrograph of a young wheat-leaf cell by A. J. Hodge, F. V. Mercer, and J. D. McLean), and (2) mitochondria and wall (unpublished micrograph of a beet cell by J. F. Farrant, C. Potter, R. N. Robertson, and M. J. Wilkins). Key: n = nucleus, v = vacuole, m = mitochondria, w = wall, p = plastid, t = membrane.

surface membrane, this seems a plausible supposition. If the resistance to diffusion were distributed evenly through the bulk of the particle, the average diffusivity would be $2 \times 10^{-11} \text{ cm}^2/\text{sec}$. The mitochondrion therefore has the requisite property of a high resistance, which would act as a barrier to leakage of any salt which had been accumulated within.

It has already been mentioned that the mitochondrion seems to be capable of maintaining chloride internally in a higher concentration than would be expected from the Donnan relationship. Robertson, Wilkins, Hope, and Nestel showed that the concentration of chloride in the mitochondria was proportional to the oxygen uptake. Further, they calculated the rate of ion accumulation necessary to maintain the concentration of chloride internally, assuming leakage at the rate expected from knowledge of the diffusion constant.

They showed that the rate of accumulation would be of the right order of magnitude to correspond to the hypothesis of the relation to hydrogen and electron transport. In this connection it may be significant that many believe that the cytochrome system is located in the surface membrane of the mitochondrion. Perhaps it is here that the first stage of accumulation from the free space takes place.

The problem of accumulation by cells may therefore have become the problem of accumulation by mitochondria, but even if mitochondrial accumulation is found in subsequent work to be a general phenomenon, this does not necessarily mean that accumulation in the cell takes place in this way. Among the outstanding difficulties, for instance, is the transference to the vacuoles of salts accumulated by mitochondria. Very little is known about the relationship of mitochondria to the inner surface of the cytoplasm which borders

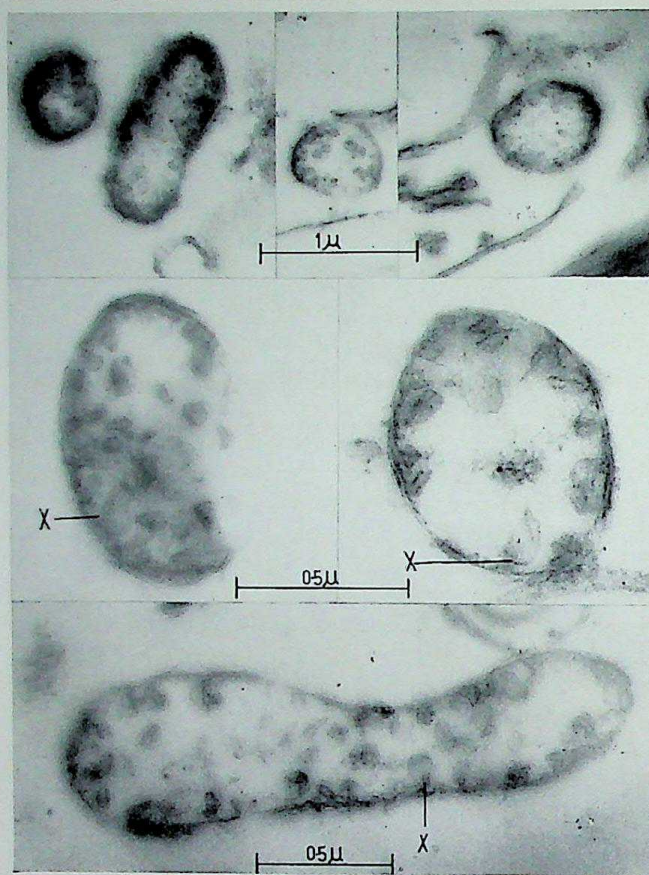


FIGURE 5 - The morphology of mitochondria illustrated by electron micrographs of sections of red beet tissue [10]. Internal double membranes resembling Palade's cristae are to be seen at points marked X.

on the vacuole, though mitochondria are seen to move readily in the protoplasm streaming round the cell and many of them frequently come into contact with the surface of the vacuole. It is possible that mitochondria would pick up ions in one part of the cell and, due to change in their metabolic activity, lose them in another.

From the point of view of comparative physiology, the secretion of HCl by the gastric mucosa of animals is of the greatest interest in relation to ion accumulation by plants. When hydrogen ions are passed to the lumen of the stomach, hydroxyl ions in equivalent amount form bicarbonate ions which pass to the blood. The evidence suggests that the hydrogen ions are those of respiration, and that the primary step is the separation of hydrogen ions and electrons at the cytochrome system (R. E. Davies [8], E. J. Conway [6]). Such separation occurring at an oxidation-reduction step, when an electron passes through a resonance system in a membrane impermeable to cations, may be the primary step in certain kinds of secretion. This hypothesis, however, does not necessarily fit all kinds of secretion; active transport of sodium through frog's skin, for example, definitely exceeds the rate calculated from the oxygen uptake (K. Zerahn [25], and A. Leaf and A. Rensham [16]). Perhaps eventually several mechanisms of active ion transport will be found.

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Decorative etching and the science of metals

CYRIL STANLEY SMITH

The revealing of structure by etching is a comparatively recent development in metallurgy. As this article shows, however, this possibility has for centuries been utilized by craftsmen making weapons such as swords and, later, gunbarrels. In this art the metalworkers of Europe were far behind those of the Orient. The products of Damascus were extensively distributed and widely famed, but the art found its highest expression in the seclusion of Japan.

The modern science of metallography was born on 28th July 1863, when Henry Clifton Sorby wrote in his diary, even though mistakenly, 'Discover the *Widmanstättisch* figure in [Lowmoor] iron'. It reached maturity four decades later, when Roozeboom applied the phase rule of Willard Gibbs to the many empirical observations that had accumulated in the intervening period. However, a long period of gestation had preceded birth, involving both philosophical speculations on structure generally and the use by scientists and craftsmen of fracture or etching to reveal something related to internal structure.

Figure 1 shows one of Sorby's photomicrographs which was shown at a British Association meeting in 1864, though not published until 1887 [1]. His first published illustrations were those impressed directly from deeply etched steel blocks in the columns of a Sheffield newspaper, probably in 1865¹ (figure 2). This technique, like its name, 'nature-printing', he had borrowed from the Viennese master printer Alois Auer, who in 1853 had published a demonstration of many kinds of typographic reproductions of things ranging from bats' wings and lace to etched stones and meteorites. A decade earlier P. M. Partsch's book on meteorites [2] had been illustrated with a print from an etched meteorite (figure 3) displaying beautifully the structure named after Widmanstätten, who had first revealed it by etching about 1807.

Etching had been used previously for other scientific purposes. In a paper which he claimed to have written in 1761, but which was not published until 1775, Grignon remarks that the intrinsic heterogeneity of iron can be shown by the

action of acids [5]. J. J. Perret independently discovered this in 1771 [6], and following him the 'acid test' became a common means of distinguishing between iron and steel. In 1798 B. F. J. Hermann (see later) published illustrations of etched metal surfaces. In 1817 J. F. Daniell wrote 'On the Mechanical Structure of Iron Developed by Solution . . .' and clearly stated the importance of the subject and the value of macro-etching [4]. D. Kirkaldy, in 1862, published drawings (figure 4) of a number of etched samples of wrought iron and related the fibre structure to mechanical properties [3].

Behind this relatively modern work by scientists and engineers there was, however, a long history of etching by artisans to produce decorative surfaces.

THE PATTERN-WELDED BLADE

The damask or 'water' of Islamic swords is the best-known etched structural pattern. Most of our story will deal with Oriental metalwork, but it begins with a European technique of much interest, that of the Merovingian pattern-welded blade. These blades have been found in many Viking sites, but they were also used by Roman soldiers at the end of the second century and they are found widely throughout Europe in sites dating to the tenth century, when they suddenly cease. It seems possible that they all derive from a single source on the Rhine. Their manufacture and history have been reported in detail by A. France-Lanord [7]. From our present standpoint their interest lies in the rather complex welded patterns down the centre of the blades. Cassiodorus (c. A.D. 575), secretary to Theodoric the Ostrogoth, thus wrote to a Vandal king thanking him for a gift of some fine swords: 'Their centres have beautiful grooves cut into them, which seem to be

¹ The newspaper clippings themselves are preserved in a volume of Sorby's papers at Sheffield University Library. They are undated, but Sorby's diary shows that he was working on the process in March 1865.

covered with little worm-like markings. Shadows of such variety play there that you would suppose the metal to be interwoven rather than just reflecting different colours.'

The point of one of these swords, excavated from a sixth-century site in Lorraine and recently repolished and etched, is shown in figure 7. The pattern results from welding together piled strips of two different kinds of metal (carbon-free, and with about 0.15 per cent carbon respectively), twisting them, and then welding the twisted rods together side by side to form the core of the sword. The cutting edge is a thin layer of the same low-carbon steel, sandwiched symmetrically in iron which covers almost its whole extent. The necessary forging undoubtedly produced a better metal than a less complicated procedure would have done, and the marks evidently came to be regarded as a kind of identifying trademark of a superior sword. To be visible on the surface the patterns must have been developed by some kind of simple metallographic procedure, most probably by etching with a vegetable acid such as fruit juice or sour beer, or with a corrosive mineral like vitriol.¹

Swords somewhat of this kind were being manufactured in Tibet in the nineteenth century. The centre of the blades consisted of a welded flat array of parallel rods of alternately hard and soft material bent in hairpin form. Although in some specimens the texture was revealed by very deep scraping following the lines of softer material and so producing a strong intaglio pattern, in others the texture was revealed only as a varying roughness resulting from transverse abrasion (figure 8).

THE ETCHING OF ARMOUR

In Europe, as has been noted, the production of these swords ceased in the tenth century, and others with higher carbon content and invisible texture took their place. Etching reappeared towards the end of the fifteenth century, when it was widely used for the etched decoration of armour, and, as an outgrowth of this, for the preparation of plates for intaglio printing [8]. Figure 6 shows a detail of a suit of armour made for the Duke of Brunswick about 1540. The design is entirely due to the artist's application or removal of an appropriate 'stop-off' to localize the chemical action, and the structure of the metal plays no role whatever.

¹J. W. Anstee, at the British Association meeting in Sheffield, 1956, reported the duplication of a blade of this kind using wrought iron alone, and remarked that the pattern could be seen on a polished blade without etching, supposedly as a result of local differences of slag content.

It is indeed surprising that the armourers did not resurrect the idea of using decorative forged textures, but an examination of scores of pieces of European arms and armour has disclosed only a single example in which the texture of the metal is visible. This is a sword, made in Munich about 1540 (figure 5), that contains visible streaks due to forging an inhomogeneous metal. These streaks were probably unintentional, although they do in fact add substantially to the general pictorial effect in the etched area representing the sky.

It is surprising, too, that the coarse grain structure of cast brass, which is easily revealed by mild corrosion, has not been intentionally used decoratively. The spangle of galvanized iron is at least partially controlled with an eye to its appearance, and early in the nineteenth century a Frenchman named Alard made opera-glass cases, snuffboxes, and the like from an etched and lacquered tin plate which he called a *moiré métallique*. This was heat-treated to develop a large grain size, sometimes locally varied to give special patterns.

THE DAMASCUS SWORD

Compared with the relative neglect of structure by European metallurgists, the enjoyment and utilization of it in the Orient is impressive. There are two distinct lines to be followed. In one the patterns are produced by forging together metals of different composition; in the other, the more interesting, crystallization effects are used.

The famed 'Damascus' blades are of the latter kind [9]. The best were made in Persia from Indian steel. They were in use even before the Islamic period, for the kingly poet Imru'ul-Qais (died c. A.D. 540) refers to a blade having wavy marks like the tracks of ants. A younger contemporary of his, Aus ibn Hajar, describes blades in these terms: 'It has a water whose wavy streaks are glistening.' 'It is like a pond over whose surface the wind is gliding.' 'The smith has worked out in it a grain as if it were the track of small black ants that had trekked over it while it was still soft.'² For centuries thereafter the swords spread widely with the Islamic faith, and references to the ant tracks became a cliché among poets.

The making of these blades provided a great challenge to European metallurgical skill, for they are of very high carbon content (1.5-2.0 per cent) and difficult to forge. It was in fact not until 1823 that they were duplicated, by the French metallurgist Bréant. In 1840 Paul Annosov established

²The writer is indebted to Professor G. E. von Grunebaum for these early references and their translation.

a Russian factory for making them by Bréant's methods. Although Annosov understood their nature less clearly than Bréant did, he nevertheless makes a classic comment on the value of a visible structure in controlling production operations: 'Europeans have not had the experience of the Orientals in recognizing the modification which steel undergoes during forging. Their inferiority comes from the fact that they have no visible signs of these modifications before their eyes. But when they have to treat Damascus steel, they will soon come to understand the disadvantage of their inexperience, and each of them will know that the disappearance of the *moiré* at the forge represents an alteration of the metal attributable to the lack of skill on the part of the smith.' It is interesting to note that by this time Indian smiths had abandoned the art of handling very high carbon material, though they had learned to operate at higher temperatures and were melting steel of a lower carbon content, which is much easier to forge.

Figures 9-11 show some typical patterns on Damascus blades. The structure was developed on the polished surface by the use of a solution of a mineral called *zag* (probably a natural ferric sulphate), although a sixteenth-century Italian writer refers to the use of fruit juices for reviving the pattern on a worn blade. The dark- and light-etching areas are composed, respectively, of approximately eutectoid steel and approximately eutectic cast iron; the latter appears whiter because of its high concentration of iron carbide. The pattern derives directly from the structure of the cake of steel from which the blade was formed, and an essential part of the smith's skill was to forge at a temperature low enough to avoid re-solution of the carbon, and in such a manner that the structure of the ingot was not distorted beyond recognition. Simple compression would magnify the structure, while if the sword were drawn out without increasing in width, the structure would elongate into invisible fibres and the metal would become as uninteresting as any modern rolled piece of steel. An intermediate practice was evidently followed. The microstructures of transverse sections indicate that the finished sword was one-third to one-tenth the thickness of the casting, and there is rarely evidence of welding.

Although many of the most beautiful blades have an appearance that obviously originates in a section through a slightly distorted dendritic structure (figure 9), others (for example, figure 10) display the carbide network in a distribution and connectivity that could not be derived from the

normal structure of a casting. There is, however, no doubt whatever that the structure of the cake of steel from which the sword is forged is basically responsible for the texture of the blade. The cakes, at least in India, where the steel was called *wootz*,¹ were made by intensely heating in a crucible a mixture of wrought iron—in the form of sponge, granules, or plates—with wood, the latter serving as the carbonizing agent. It seems to the writer most probable that the process was sometimes, perhaps often, not carried to the point of complete fusion, but only to the state of a mush of unfused grains of gamma iron surrounded by molten cast iron. Occasionally, indeed, plates of wrought iron seem to have been merely carburized and 'brazed' together with white cast iron and subsequently forged out, the grain resulting from the finished surface being cut so as to expose underlying lamellae.

Some of the most prized blades have lateral markings known as Forty Steps or Mohammed's Ladder, such as are shown in figure 11. Tschernoff suggested that these result from radial dendritic segregation in the cake of cast steel used for forging the blade, but a close inspection of the pattern lends no support to this idea. It seems virtually certain that it was produced by cutting transverse grooves on the surface prior to the last stage of forging, so as to change the angle of intersection of the exposed lamellae, and hence their direction and spacing. The transverse markings on the kris to be discussed below were analogously produced.

ORIENTAL FORGED TEXTURES

In addition to the crystallization damask of the high-carbon swords, a simpler texture produced by forging alone was popular in the Near East and India, especially for the manufacture of gun-barrels. It was repeatedly, though erroneously, suggested in Europe that the true Damascus swords resulted in this way, and factories for the manufacture of composite forged blades were established in France, Italy, and Russia. A German metallurgist, B. F. J. Hermann, studying the problem in St Petersburg, read a paper [10] before the Russian Academy of Sciences in 1798 in which he gave what seem to be the earliest published illustrations of an etched metal surface (figure 12).

Both the earliest and the best work of this kind was Oriental. The most striking is the kris of the Malayan archipelago. The weapon seems to have

¹ *Wootz* was made in India, notably in Hyderabad, Madras, and Mysore, from about the beginning of the Christian era.

originated in the thirteenth century in Java, with welded patterns appearing not later than the fifteenth century. Strong contrast was produced in the design by the use of steels differing greatly in corrosion resistance (including, it is said, meteoric iron, and in more recent times even nickel and European stainless steels); by forging at a low temperature to minimize diffusion; and by employing etching reagents such as fruit acids containing arsenic. Five different kinds of patterns are shown in figure 14. They all involved layering of the metal in a predetermined manner, and subsequent contouring of the piece by forging and cutting so that the layers would be appropriately sectioned on the final surface.

The most attractive and serviceable products of the mixed-metal forging technique were gunbarrels. Figure 15 shows a seventeenth-century Indian flintlock gunbarrel which was deeply etched to show in relief the contorted mixture of steels of different composition; figure 13 shows an eighteenth-century Turkish carbine, more sophisticatedly worked, and etched only enough to display the pattern. The manufacture of these so-called Damascus gunbarrels was established in Europe in the eighteenth century and, like that of the swords, had an important effect on European metallurgy.

The establishment of a factory in Sweden was described in 1773 by Peter Wäsström, who remarked on the effects of acid on different kinds of steel. Wäsström's paper aroused the interest of the great metallurgist Sven Rinman, who in the following year presented an extensive memoir [11] on the etching of iron and steel. He showed that when treated with acid, cast iron or steel always left behind a black sediment like black-lead, but that this was not found if the iron had been treated to remove phlogiston. He clearly anticipated, in everything except experimental elegance, Bergmann's more famous observations on the role of carbon in steel and iron, and though virtually unknown the paper is one of the classics of metallurgy.

Thus the duplication of an Oriental gunbarrel in a Swedish factory led to a metallurgist's study which inspired a chemist's investigation; this in turn was the basis for the formulation in France of a clear statement of the role of carbon in steel; this statement was an important factor in the Chemical Revolution. This sequence of events provides a fine illustration of the international and interdisciplinary factors involved in the growth of science.

THE JAPANESE SWORD

Japanese metalworkers understood the structure and nature of metals better than any others, and for centuries they made visible the structures of both ferrous and non-ferrous metals for both technological and aesthetic purposes. There was, unfortunately, no interaction with European science.

The Japanese sword is the supreme example of metallurgical art. It is composed of many layers of steel (often 2^{20}), worked by a complicated folding-welding-and-forging operation that uses a flux designed to remove the gangue from the crude metal and to control the carbon content [12]. The swords were given a final hardening while partially coated with a thermally insulating material that permitted the edge of the blade to be quenched rapidly while the body cooled more slowly and hence was not martensitic in structure. By adjusting the distribution of layers of steel of different hardenability, and by varying the outlines of the insulating compound, extremely wide ranges of surface patterns were produced, many of great beauty.

From certainly as early as the fifteenth century—and probably as early as the twelfth, and perhaps even earlier—the surface of these blades was finished by a sophisticated polishing operation that reveals the structure in almost metallographic detail. The finishing is said to have been done mechanically with a fine-grained limestone alone, but the appearance suggests that some chemical action may have been involved. It is unlike any European polish, for the harder material is definitely more matt than the soft, except in the intermediate zone where the two constituents are intermingled. The visible grain, which shows well in the unhardened portion of the blade surface, arises from variations of slag inclusions and carbon content in the different layers of metal as they are exposed at the surface. Details of a sword after a light repolish and metallographer's etch is shown in figure 16.

The writer has discussed the metallography of some of these blades in a recent paper [13]. An interesting feature is the presence of spots, known as *niye*, visible to the naked eye in the part of the sword that had cooled slowly enough to allow most of the material to become pearlitic. Figure 17 shows such spots on a sword polished in Japan, and figure 18 a similar one prepared metallographically. The spots are seen to be of martensite, resulting from abnormally large grains of austenite scattered through the metal.

The highest skills also were used in making the

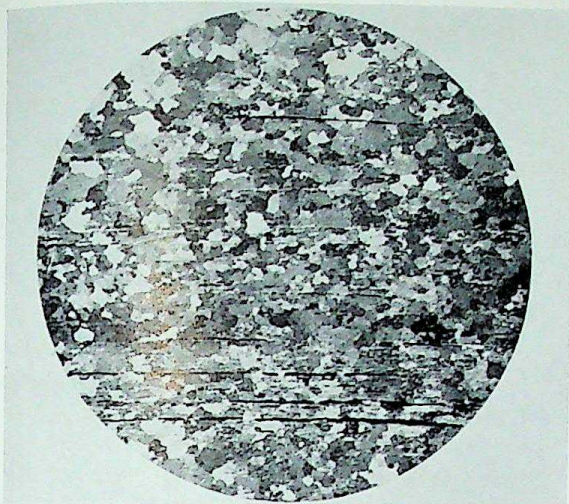


FIGURE 1 - Photomicrograph of etched wrought iron, longitudinal section (Sorby, 1887). ($\times 9$)

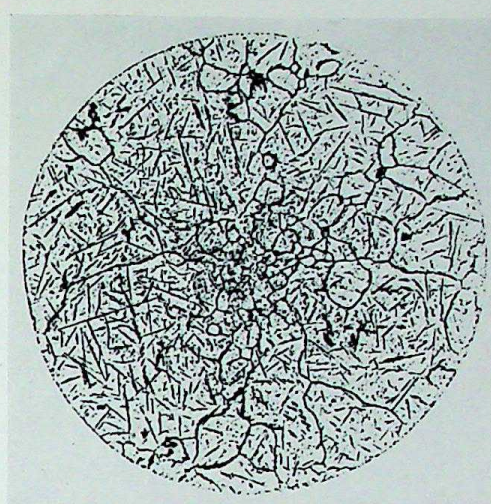


FIGURE 2 - Direct nature-print from etched converted steel bar (Sorby, c. 1865). (Enlarged to $3/2$ in reproduction.)

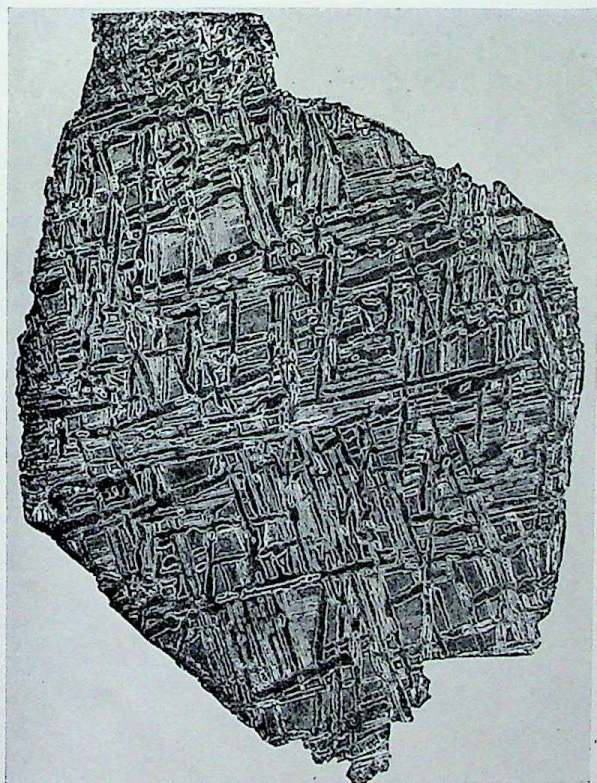


FIGURE 3 - Typographical imprint of an etched meteorite (Parsch, 1843).

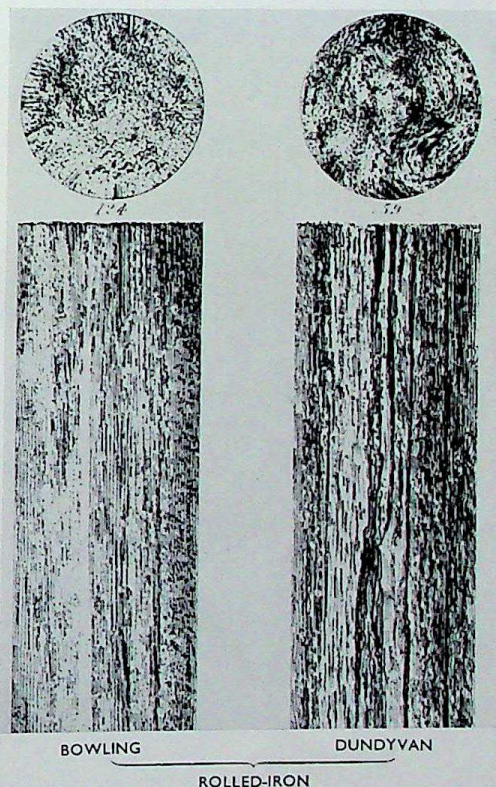


FIGURE 4 - Texture of wrought iron developed by etching (Kirkaldy, 1862).



FIGURE 5 - Etched hunting sword made by Ambrosius Gemlich (Munich, 1540). (Natural size)
CC-0. In Public Domain. Gurukul Kangri Collection, Haridwar

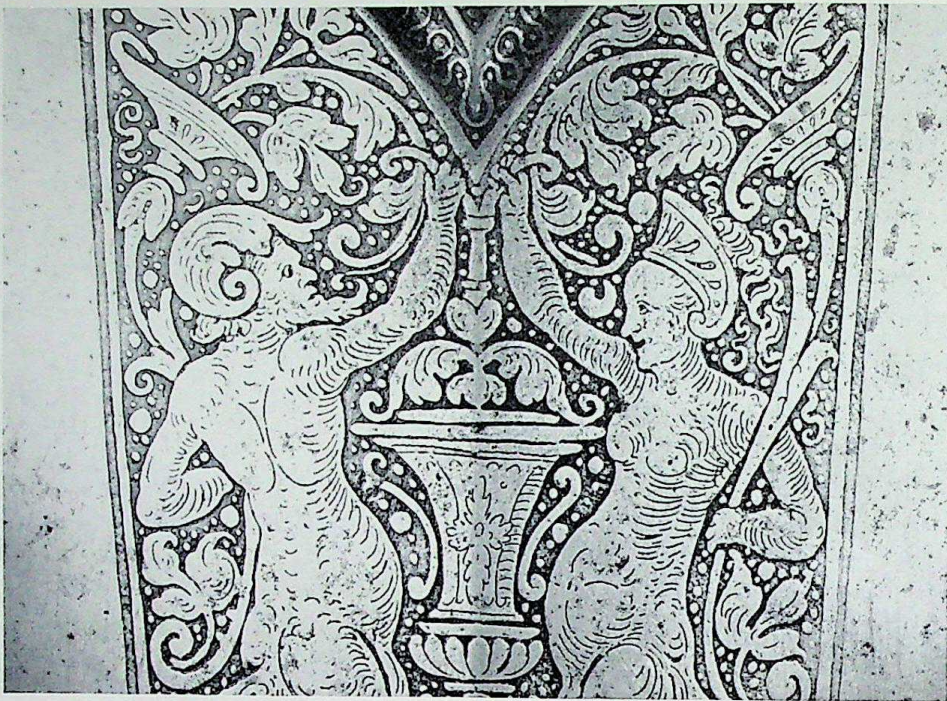


FIGURE 6 – Detail of etched breastplate of armour of the Duke of Brunswick, c. 1540. (Natural size)



FIGURE 7 (Left) – Tip of pattern-welded blade (Lorraine, c. sixth century). Repolished and etched. ($\times 1.14$)

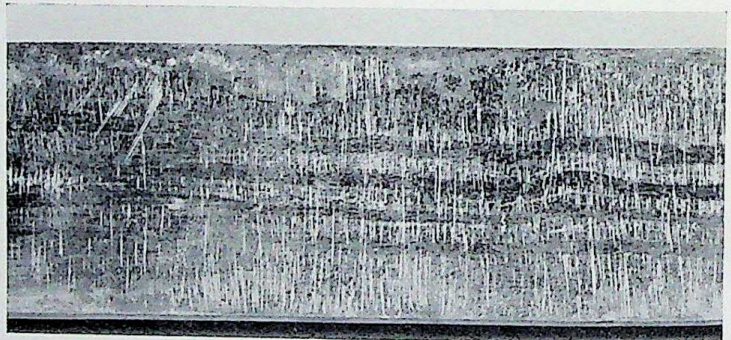


FIGURE 8 – Sword from Derge, Tibet, nineteenth century or earlier (Chicago Natural History Museum). (Natural size)

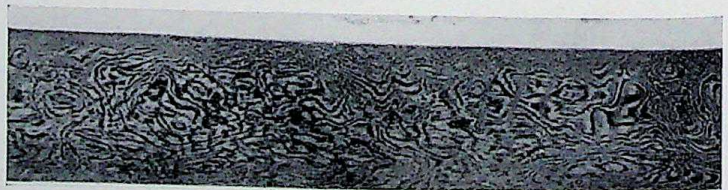


FIGURE 9 – Persian straight sword (Isfahan, eighteenth century). Damask shows distorted dendritic structure. (Natural size)

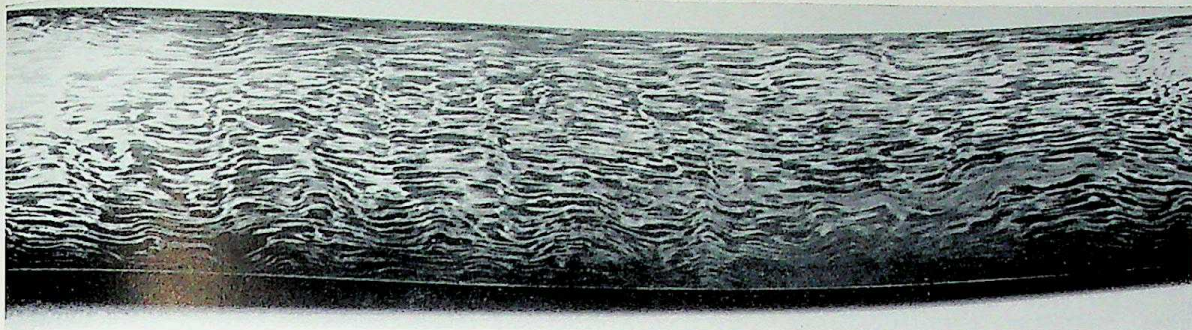


FIGURE 10 – Persian sword, late seventeenth century. (Natural size)

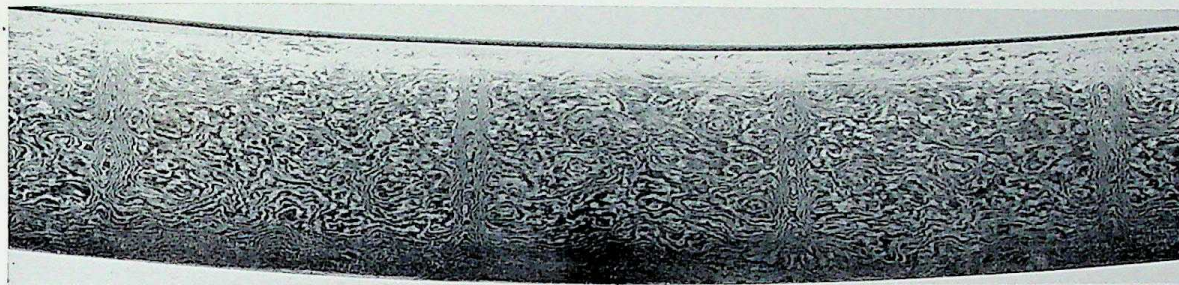


FIGURE 11 – Persian sword of Indian form, with crossmarkings known as 'Mohammed's Ladder'. (British Museum. Photograph by courtesy of Mr Herbert Maryon.)

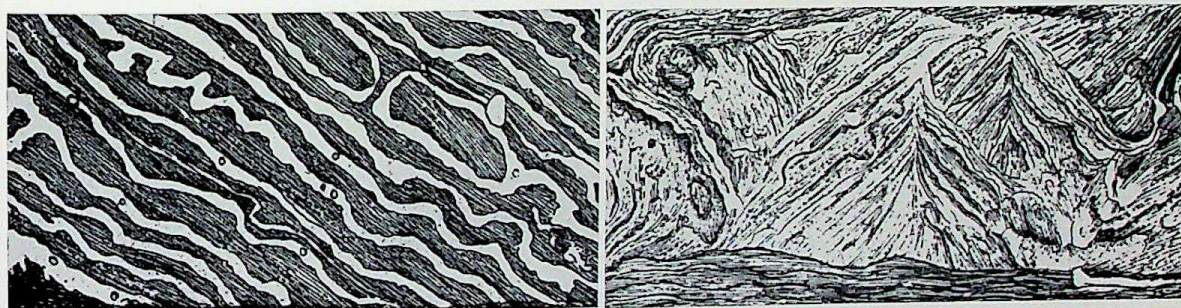


FIGURE 12 – Artificial damask made by forging (Hermann, 1798). These are believed to be the first published illustrations of an etched metal surface.



FIGURE 13 – Barrel of a Turkish carbine, eighteenth century. (Victoria and Albert Museum.) ($\times 1.1$)

Figures 5, 6, 9, 10, and 15 are reproduced by permission of the Trustees of the Wallace Collection.

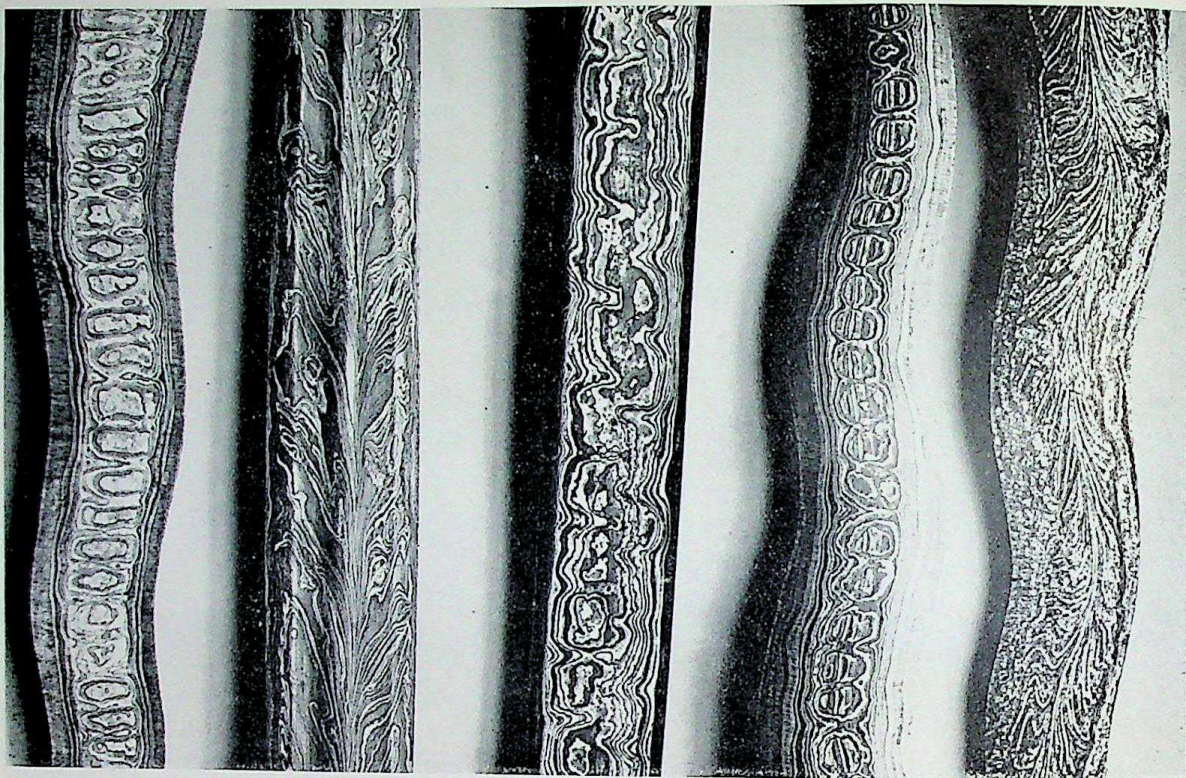


FIGURE 14 - *Blades of five Malayan kris. (British Museum. Photograph by courtesy of Mr Herbert Maryon.)*

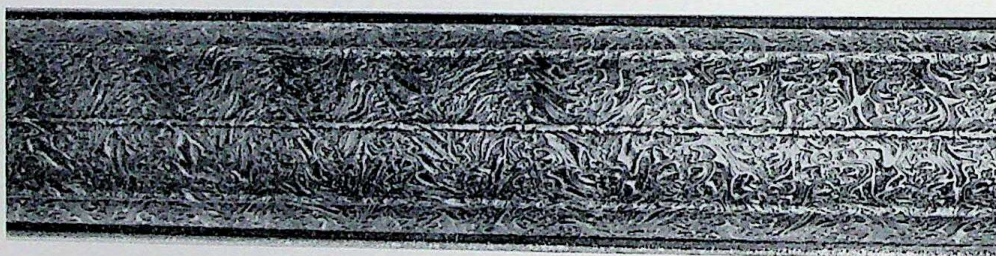


FIGURE 15 - *Barrel of flintlock gun (Indian, c. 1650). (Natural size)*

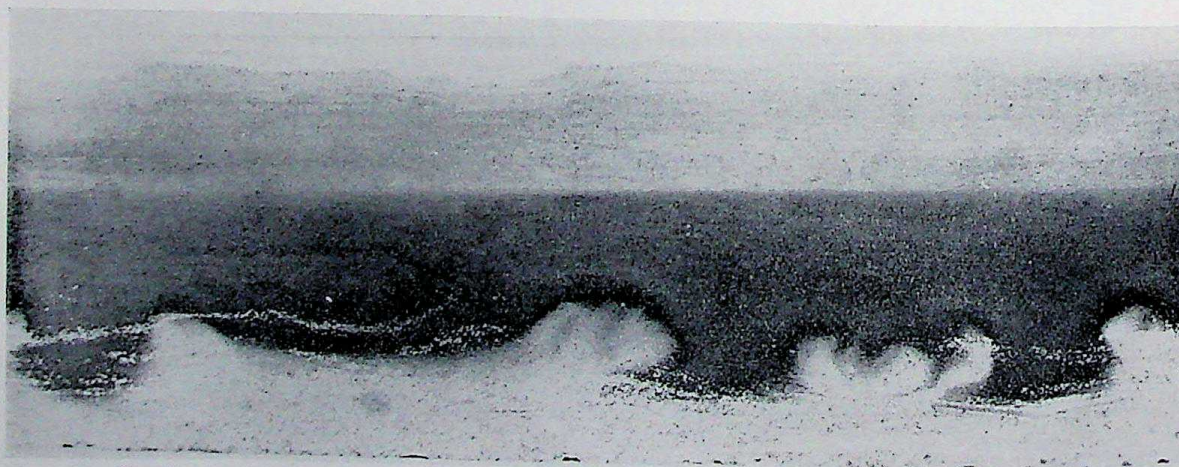


FIGURE 16 - *Unsigned eighteenth-century Japanese sword. Repolished and lightly etched. (Reproduced by courtesy of the Associazione Italiana di Metallurgia.) ($\times 2.5$)*

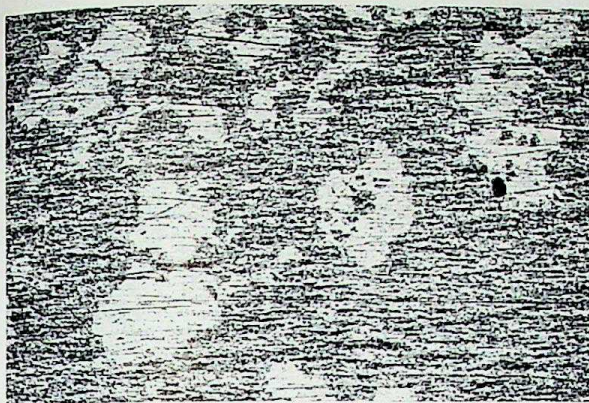


FIGURE 17 - Niye spots in sword by Masamune (1264-1343) with normal Japanese finish. (Collection of Capt. A. D. E. Craig.) ($\times 85$)

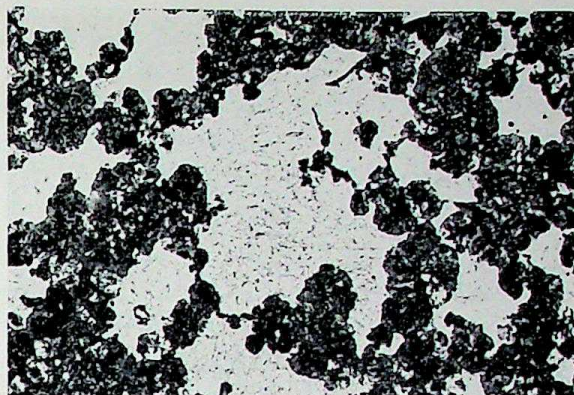


FIGURE 18 - Niye spots on a sword by Nobuyuki (nineteenth century), metallographically repolished and etched. ($\times 100$)

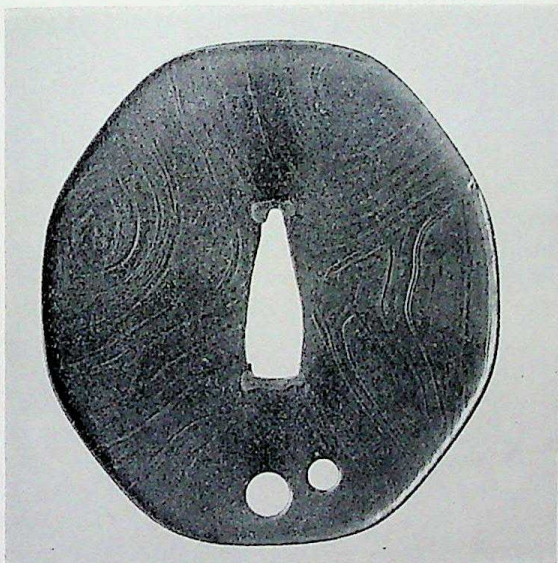


FIGURE 19 - Iron mokume swordguard, signed Miochin Munetane (c. 1840).

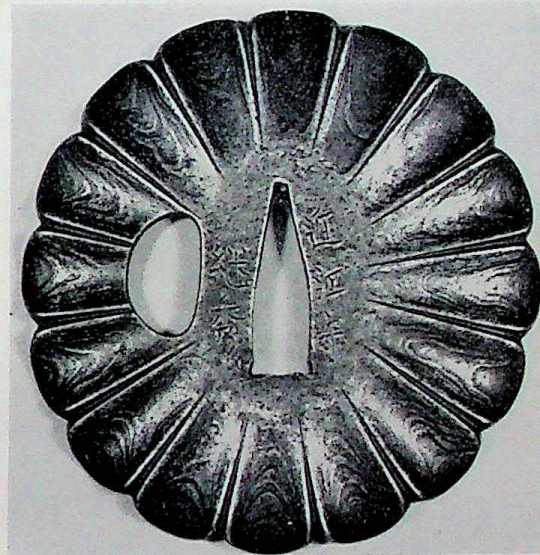


FIGURE 20 - Carved iron swordguard with mokume texture, signed Tsugihide, c. 1800. (Victoria and Albert Museum.)

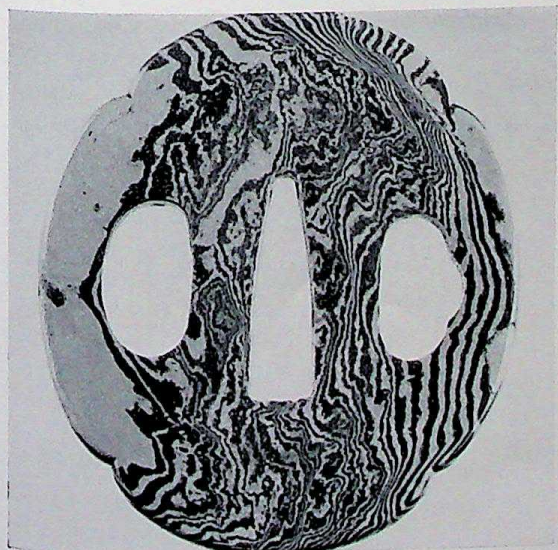


FIGURE 21 - Soft metal mokume swordguard, signed Miochin Munetane (c. 1840). (Victoria and Albert Museum. Crown copyright.)

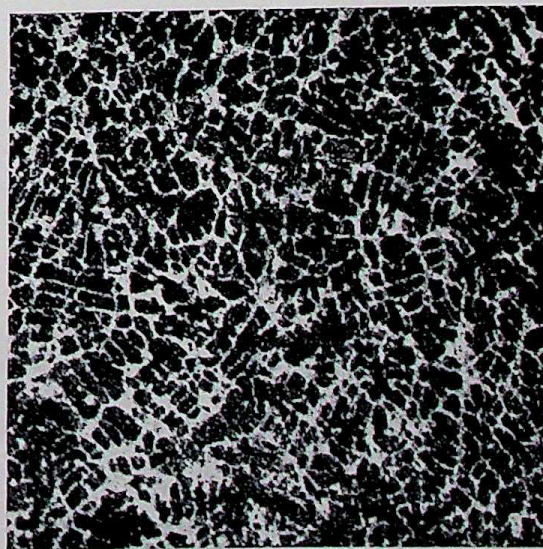


FIGURE 22 - Original surface of a shibuichi swordguard, signed Masamune (1264-1343). (Victoria and Albert Museum. Crown copyright.) ($\times 85$)

fittings for the sword, particularly the guard (*tsuba*) and the little metal pieces at the two ends of the handle (*fuchi-kashira*). *Tsuba* made from the fourteenth to the seventeenth centuries were usually of iron and show a remarkable feeling for its nature. The earlier workers prided themselves on showing the very 'bones' of the metal. Surfaces would be proudly displayed showing marks from anvil roughness or pitting resulting from scaling or corrosion, sometimes accentuated with a few exquisite inlaid details in gold or silver. One of the most interesting techniques is that known as *mokumé* (woodgrain), which is related to that of the welded Damascus barrels and swords discussed above, though the designs are simpler and more pleasing. A mid-nineteenth century example is shown in figure 19. Figure 20 shows an iron guard made by forging together flat lamellae to give texture in the carved curved surfaces of the chrysanthemum petals.

In the eighteenth century and later, non-ferrous metals became common for sword furniture, usually finished by intricate chiselling, punching, and inlay. Several different copper and silver alloys were developed solely for the finely coloured patina that they show after suitable pickling, and these were sometimes combined to make the *mokumé* effect. One of these appears in figure 21. The dark areas are sectioned lamellae of the alloy known as *shibuichi*, an alloy of copper, containing approximately one-third silver, which has a re-

markable greyish-green sheen unmatched in any other material. When properly pickled the eutectic network of silver-rich material stands in slight relief, simultaneously giving both the optical effect characteristic of the alloy and protecting from wear the patina on the copper surface. The alloy *shakado* (copper with about 4 per cent gold) also often shows a faint microstructure due to coring. Figure 22 is a photomicrograph of the surface of a *shibuichi* guard signed by a *tsuba* maker, Masayuki, who died in 1769. This is the original surface, finished approximately two centuries ago, yet it is little inferior to one that would be prepared today by modern metallographic techniques. Had such surfaces been available to seventeenth-century European microscopists, metallography would have begun then. Power, Hooke, and Leeuwenhoek could see no significant detail in surfaces distorted by scratching, burnishing, or fracture. Unfortunately, the greater sensitivity of Oriental metalworkers to the nature and structure of metals was largely aesthetic and was not paralleled by scientific speculation. It was in Sorby, as we indicated at the outset, that philosophy and craftsmanship first united.

ACKNOWLEDGMENTS

The writer gratefully acknowledges grants from the Guggenheim Foundation and the U.S. National Science Foundation. He has benefited greatly from conversations with Mr B. W. Robinson, Mr Herbert Maryon, Mr D. Tudor-Williams, and Mr A. France-Lanord.

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Crocuses

E. F. WARBURG

The evolution and classification of the various *Crocus* species presents several points of general interest to botanists, but the genus is one that has a much wider appeal. It is widely cultivated as a garden flower—where its bright coloration and generally early flowering make it particularly attractive—and a considerable range of varieties has been developed. Some further development of cultivated forms seems possible, especially within the *chrysanthus* group, which has permitted the introduction of a series of blue flowers.

The genus *Crocus* consists of some 80 species with their main centre in the eastern Mediterranean region. Several species occur in Spain and north-west Africa, but the number of species in comparable areas increases eastwards, the largest number occurring in the Balkans and Asia Minor. The most easterly species, *C. alataicus*, is an outlier in the Alatau mountains in central Asia. The most northerly species, *C. caeruleus* (*C. albiflorus*), occurs high in the Alps. None is native in Britain.

Saffron, obtained from the styles and stigmas of *Crocus sativus*, is the only product of economic importance derived from any species of the genus. This species is cultivated in the greater part of the Mediterranean area and eastwards to Kashmir. It has been cultivated from ancient times and was formerly used for its medicinal as well as for its flavouring and colouring properties, which are still so widely esteemed. The word *Crocus* is of ancient Semitic origin, the word taking the form *κροκος* in ancient Greece. The word 'saffron' is of Arabic origin. Both words were originally applied to both the plant and the drug, the differentiation existing today being comparatively modern.

The origin of the cultivated saffron is not known. No plants having both the large flowers and long stigmata of the cultivated plant are known in the wild state, but allied plants extend from Italy to Persia. No doubt the cultivated saffron, which is very uniform throughout its range, was derived from one of them. It is completely sterile, seed not being produced. It has been shown to be triploid ($2n = 24$) with very irregular meiosis, so that the sterility is accounted for. Allied diploid forms are known. In England the true saffron was formerly cultivated in the eastern counties, especially in the area round Saffron Walden in Essex, which takes its name from the plant.

It has been suggested by W. B. Crump and W. A. Sledge that another species, *C. nudiflorus*, was also grown for saffron, particularly in the Midlands,

and that it was introduced there by the Knights of St John. *C. nudiflorus* grows well and is one of the very few species that spreads by stolons and not only by splitting of the corm or by offsets. It has thus become naturalized in England in meadows in a number of places within the area of its former cultivation. Its native area of distribution is in the Pyrenees and Spain. It was first recorded as a naturalized British plant at Nottingham in 1738. Although this species has considerably smaller styles and stigmas than *C. sativus*, the latter does not, as a rule, flower freely in England and demands special conditions: a preference for *C. nudiflorus* would therefore be understandable.

Crocuses have long been cultivated in Britain as garden plants. In J. Gerarde's 'Herball' (1597) crocuses are described that are clearly *C. vernus*—a name conveniently used in an aggregate sense for a group of species and their garden descendants—and *C. flavus* (*C. aureus*). Another is possibly *C. versicolor*, and there are at least two autumn species, *C. sativus* and probably *C. nudiflorus*.

In J. Parkinson's *Paradisi in Sole* (1629) 27 spring-flowering and four autumn-flowering kinds are enumerated. Most of the spring-flowering ones are varieties of *C. vernus*, but there are also—besides *C. flavus*—*C. angustifolius* (*C. susianus*), *C. biflorus*, *C. versicolor*, and possibly *C. × stellaris*. The autumn ones are difficult to identify, but they include *C. sativus*, *C. nudiflorus*, and probably *C. serotinus*. Crocuses were also much cultivated in Holland and are described in a number of Dutch books of the seventeenth century; the same species seem to have been grown in both countries.

In J. Sabine's account (1830) of the spring *Crocus* then grown in the garden of the Horticultural Society—two hundred years after Parkinson—no fresh species occurs, although the number of garden forms grown had increased enormously (57 varieties of *C. vernus* are enumerated). This is rather remarkable, because, though the species

then already in cultivation—with the exception of the south Russian *C. angustifolius*—are reasonably accessible in nature, they are no more so than a number of other species that were ignored.

These early cultivated species are conveniently considered separately.

C. vernus. This name is conveniently applied collectively to a group of closely allied plants, variously regarded by different authors as species or subspecies. The form most closely resembling the cultivated plants is *C. purpureus*, which occurs in a wild state in central Italy. This species is probably responsible, at least mainly, for the Dutch white, purple, and striped Crocuses that are today (with the Dutch yellow) the members of the genus most commonly grown in gardens.

C. caeruleus, a much smaller plant from the Pyrenees, Alps, and other European mountains, may also have played a part, but it is not very easy to grow and is not commonly grown today. Despite its name, it is usually white-flowered in nature. *C. vernus* is of variable colour in the wild, and differently coloured forms were in cultivation at an early date. The numbers of varieties increased rapidly and were given vernacular names by the Dutch growers, at least as early as Sabine's time, though he himself unfortunately gave nearly all of them Latin ones. Development has continued more slowly of recent years, and it would probably now be more difficult to get together a collection of 57 named varieties than in Sabine's time. Like *C. nudiflorus*, *C. vernus* has long been naturalized in Britain, being first recorded from Nottingham in 1796. These naturalized colonies—for example, one still existing in south Berkshire that has been known since soon after 1800—give a picture of the earlier forms. Modern forms (figure 17) differ little except in their larger size.

No wild form of this group appears to have been examined cytologically, but studies on cultivated varieties, mainly by K. Karasawa, who is responsible for most of the cytological work on the genus, indicate that the diploid number is 16. This number is found in some garden forms; others show the triploid number 24 or the tetraploid number 32, and there are a smaller number of aneuploid forms with various numbers between 18 and 30. As with many other garden plants (e.g. *Narcissus*), an increase in chromosome number is correlated with an increase in size, and large-flowered varieties—e.g. 'Excelsior', whose diploid number is 29—tend to have high numbers. These garden varieties are largely fertile and so give rise to fresh forms. No detailed study appears to have been

made on the relation between number of chromosomes and fertility, but the high fertility is, no doubt, part of the reason for the large number of varieties.

Most of the striped varieties show an irregular type of striping, not known elsewhere in the genus. They also frequently have somewhat misshapen flowers, occurring unexpectedly among purple clones. The striping is possibly due to a virus similar to that causing 'breaking' in tulips, but the matter has not yet been properly investigated.

C. flavus. This species, better known as *C. aureus*, is a native of the Balkans and western Asia Minor and was probably introduced into cultivation by the Dutch botanist Clusius in 1579; it was certainly in cultivation in 1665. Today it is represented in gardens chiefly by 'Dutch Yellow', though wild forms (figure 8) and a much paler variety, *sulphureus*, are also grown. The wild plant appears to vary little except in the depth of colour. 'Dutch Yellow' is a relatively robust plant and is completely sterile. It is now represented by at least three clones, differing in the colour and markings of the flower. Besides *sulphureus*, a number of other varieties—such as the cream-white *lacteus*—were formerly grown. Sabine lists nine varieties in all, but these have now almost, if not quite, disappeared from cultivation. There seem to have been no fresh developments in *C. flavus* during the last hundred years.

The diploid number of *Crocus flavus* is 8. Two clones of 'Dutch Yellow' have been reported to have numbers 14 and 15 respectively, with very irregular meiosis. The sterility of this plant is thus accounted for. Its origin must have been complex, perhaps resulting from tetraploidy followed by chromosome loss: hybridity is scarcely likely to be responsible on historical and morphological grounds. Nothing appears to be known about the reason for the sterility of *sulphureus*, whose diploid number is 8, which is normal for the species.

C. angustifolius (*C. susianus*). Like *C. flavus*, this species, yellow with brown markings on the outside, appears also to have been introduced by Clusius, but at a rather later date (1587). Parkinson describes two forms, differing in the markings of the outer perianth segments, and uses the name 'Cloth of Gold', by which the species is still known. There are still two forms in gardens, grown under the names '*susianus*' and '*susianus minor*': these appear to be those known to Parkinson. '*Susianus minor*' has a diploid number of 12, with normal meiosis; '*C. susianus*' has a diploid number of about 15, with irregular meiosis, so that it is probably a

garden derivative of the former. No further variation appears to have taken place.

C. × stellaris. This was known to A. H. Haworth (1809) and very probably also to Parkinson. It is not known wild. J. G. Baker, in 1873, seems to have been the first to suggest that it was a hybrid between *C. angustifolius* and *C. flavus*; it is morphologically intermediate between the two and completely sterile. It has a diploid number of 10, to be expected in a hybrid between the normal forms of these species. According to Karasawa, no chromosome pairing takes place, so that its suspected origin is strongly confirmed by its cytology.

C. versicolor. This species is a native of the French and Ligurian Riviera. It was early cultivated and was formerly represented in gardens by a number of forms—Sabine gives 18—but, perhaps because of the introduction of other rather similar species, these have almost entirely disappeared. It is now mainly grown in two forms, both white but with differently marked purple lines on the outside of the perianth segments. In nature, the species is prevaillingly lilac-flowered, and the persistence of the white forms in cultivation is perhaps due to their greater difference from related species (e.g. *C. minimus*, figure 6). Both diploid ($2n = 26$) and triploid forms are known.

C. biflorus. This is a member of a taxonomically difficult group of *Crocus* distinguished by the coats of the corms having horizontal rings round them (annulate) and by their spring-flowering habit. A group of autumn-flowering species with similar corms, including *C. speciosus* (figure 10), may not be closely related. Other members of the group will be considered later. *C. biflorus* itself is a native of Italy but is represented by a number of allied forms, variously regarded as varieties or distinct species, in the Balkans and Asia Minor. All the early cultivated forms, however, resemble the Italian plants and probably originated from them. They have white or pale lilac flowers, variously striped with dark purple on the backs of the outer segments. One of them (var. *parkinsonii*, figure 5), originally named by Sabine, is believed to be the same as a form known to Parkinson. Another old form, known as the 'Scotch *Crocus*', is quite sterile, like several other old garden *Crocuses*. Both these and several other varieties are still frequently grown. Three varieties in this group have a diploid number of 8. The 'Scotch *Crocus*', perhaps the most unlike the wild types, has apparently not been cytologically examined, and the reason for its sterility is not known.

A recent variety, 'Barrii', most like this group,

has a diploid number of 7 and some peculiar features in the corm tunic. Possibly it is a hybrid with one of the 6-chromosomed species of the Aureus group (e.g. *C. balansae* (figure 14), though this species is not itself a likely parent of 'Barrii').

Throughout this period, and indeed later, the autumn-flowered species, though at least three were grown, seem to have shown little variation. Whether these species are inherently less variable than some of the spring ones, or whether the lack of variation is merely a reflection of lack of interest is uncertain. The autumnal species seem never to have been as popular as the spring ones.

Since 1830 the number of species in cultivation has increased enormously, largely due to the efforts of three English horticulturists and amateur botanists, W. Herbert, G. Maw, and E. A. Bowles. Each of them collected together in their gardens as many different species of the genus as they could, and each produced a monograph on the genus (Herbert, 1847; Maw, 1886; Bowles, 1924 and 1952). Most of these species, though some of them are variable in nature, have not become the parents of new garden races, but there are developments from two of them worth considering further.

C. tomasinianus. This species was named by Herbert after its discoverer, Tommasini of Trieste, who sent bulbs to both Herbert and Maw. It grows wild in Yugoslavia. It is closely allied to *C. vernus*, differing from the latter mainly in its narrower leaves and narrower, more pointed, flowers. Of all species of *Crocus* it is the most at home in English gardens, sowing itself freely. Typically, the flower is lavender inside and grey outside; but it has varied considerably, and several selected forms are now sold; an example is 'Barr's Purple' (figure 15). It has a diploid number of 16.

During this century plants that appear to be hybrids between *C. tomasinianus* and *C. vernus* have appeared in gardens; they are usually named as if varieties of *C. vernus*. They combine the larger flowers of garden forms of the latter with the early-flowering habit and flower coloration of *C. tomasinianus*. Two in commercial cultivation are 'Vanguard' (figure 16) and 'Haarlem Gem'. 'Vanguard' is a triploid ($2n = 24$), which is consistent with its being a hybrid between *C. tomasinianus* and a tetraploid garden form of *C. vernus*.

C. chrysanthus (figures 3, 18–20). This species is an ally of *C. biflorus*, having a similar corm and, commonly at least, the same chromosome number ($2n = 8$). It differs in the colour of the flower, typically of the same golden yellow as is met with in other *Crocuses* (e.g. 'Dutch Yellow'), the shape

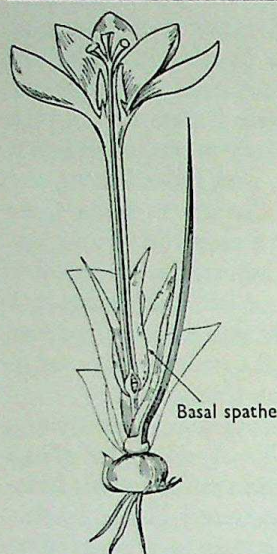


FIGURE 1 — Diagram of crocus, showing basal spathe.

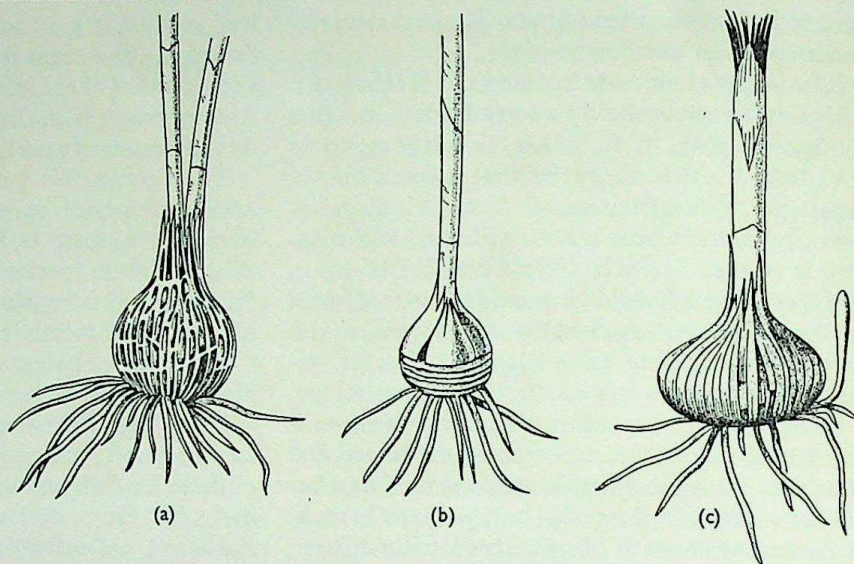


FIGURE 2 — *Crocus* corms. (a) reticulate tunic; (b) annulate tunic; (c) tunic of parallel fibres.

of the flower and the almost constant presence of a black barb at the bottom of the anthers. It is a native of the southern and western Balkans and of Asia Minor. It varies very much in nature in flower size and in colour; the latter varies from deep yellow to white, with or without external colouring. Many forms have been selected and given names; 'E. P. Bowles' (figure 3) is one.

The origin of such plants presents no difficulty, but that of other forms usually named as varieties of *C. chrysanthus* is less simple. Thus, var. *fuscotinctus* (figure 20), originally described by Baker (1873), differs not only in its differently shaped flowers with the anthers uniformly grey and without black barbs but also in its chromosome number ($2n = 10$). 'Canary Bird', which looks like a derivative of it, has the same number and a nearly regular meiosis. It seems reasonable to think that these forms represent another species; they do not, however, seem to be known in a wild state.

The situation in this group is further complicated by other species. These include *C. aërius*, with blue flowers; two plants variously regarded as separate species or as varieties of *C. biflorus*—*C. weldenii*, a Balkan plant with flowers pure white within and uniformly purplish (or white) outside; and *C. adami* from Asia Minor with blue flowers, striped outside.

Garden plants of the *weldenii* type—called 'weldenii', 'weldenii albus' (figure 4), and 'Kittiwake' respectively—were found by Karasawa to have diploid numbers of 15, 20, and 15. The first of these is thus scarcely likely to be the wild plant.

The numbers suggest, however, that a species distinct from *biflorus* is involved. It is highly desirable that wild *weldenii* material should be examined cytologically.

Many varieties of this annulate group have appeared and continue to appear. Though these are usually named as forms of *C. biflorus* (including *weldenii*) or *C. chrysanthus*, it is probable that many of them are, in fact, of hybrid origin. Of special interest are the so-called blue forms of *C. chrysanthus* (e.g. 'Blue Pearl', figure 18). These have introduced a new colour range into garden crocuses. The only wild form of this species to show bluish coloration is var. *caerulescens*, which may itself be a hybrid with *C. aërius*; it shows the bluish colour only on the outside of the flower. It seems very possible, therefore, that these blue forms, though resembling *C. chrysanthus* in flower shape and the black barb on the anthers, are hybrids with *C. aërius* or *C. adami*.

Developments in the garden *Crocus* in the near future are likely to be concerned mainly with this group, and if the size of their flowers is increased further they may well become as popular as the forms of *C. vernus* and 'Dutch Yellow'.

CLASSIFICATION

As reference has been made above to relationships between species, a little ought to be said, in conclusion, about the classification of the genus. It has proved difficult to devise any system without an arbitrary element. The most satisfactory system is that of Maw, who uses, in this order, the following

FIGURE 3 - *C. chrysanthus* 'E.P. Bowles'.FIGURE 4 - The plant known in gardens as '*C. weldenii albus*'.FIGURE 5 - *C. etruscus* 'Zwanenburg Variety' (blue) and *C. biflorus* var. *parkinsonii* (white).FIGURE 6 - *C. minimus*.FIGURE 7 - *C. sieberi* var. *atticus*.FIGURE 8 - *C. flavus* (*C. aureus*).



FIGURE 9 – *Crocus medius*.



FIGURE 10 – *C. speciosus*.



FIGURE 11 – *C. asturicus* '*Atropurpureus*'.



FIGURE 12 – *C. longiflorus* var. *melitensis*.



FIGURE 13 – *C. byzantinus*.

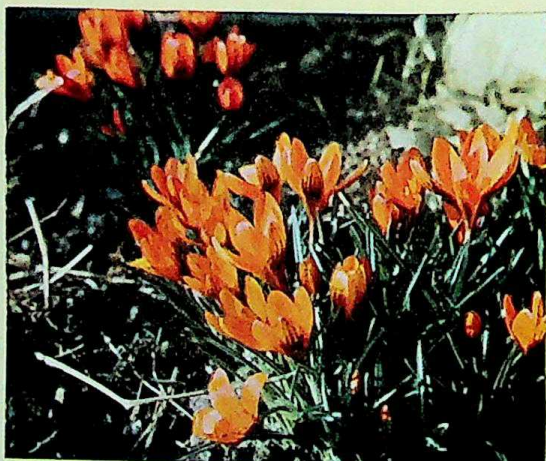
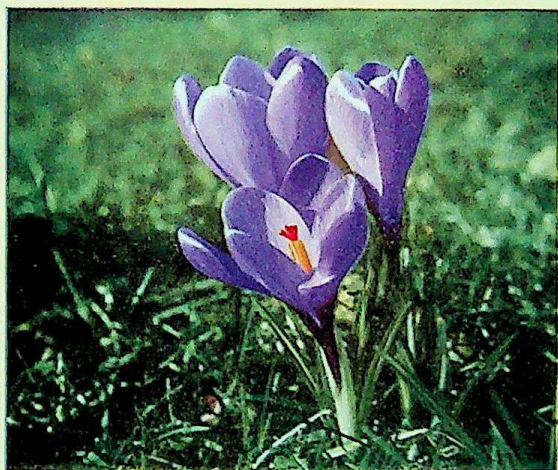


FIGURE 14 – *C. balansae* '*Zwanenburg Variety*'.

FIGURE 15 – *C. tomasinianus* 'Barr's Purple'.FIGURE 16 – *C. tomasinianus* × *vernus* 'Vanguard'.FIGURE 17 – *C. vernus*, a modern purple form.FIGURE 18 – *C. chrysanthus* 'Blue Pearl'.FIGURE 19 – *C. chrysanthus* 'Zwanenburg Bronze'.FIGURE 20 – *C. chrysanthus* var. *fuscotinctus*.(Photographs by Miss V. Finnis,
Waterperry Horticultural School)

qualities: (1) Presence or absence of a 'basal spathe' (figure 1)—a whitish bract from the top of the corm, subtending the inflorescence; (2) the type of corm coat (figure 2), whether of parallel fibres, reticulate, annulate, or interwoven into a sort of herring-bone pattern; (3) vernal or autumnal flowering; (4) flower colour. Even this system is not very satisfactory. Thus there is a group of probably allied species called by Bowles the 'Imperati Group' (including *C. minimus* (figure 6), *C. etruscus* (figure 5), and *C. versicolor*). They are recognizable by their flowers being lilac (or white) inside and usually buff outside with purple stripes; by a geographical range from the Balearic Isles through south France, Corsica, and Sardinia to Italy; and by chromosome numbers 22, 24, and 26 (numbers which also occur in species morphologically very unlike this group). Although the members of this group all have a basal spathe, *C. dalmaticus*, which lacks one, appears to be closely related to them; a further complication is that it includes some species with parallel corm-fibres and others with reticulate ones.

A more satisfactory group from the point of view of Maw's classification is the 'Aureus Group' of Bowles, e.g. *C. balansae* (figure 14) and *C. flavus* (figure 8). These are all characterized by a parallel-fibred tunic, no basal spathe, and yellow flowers (except in some forms of *C. candidus*) produced in spring. They have an eastern Mediterranean distribution and usually a diploid number of 6 (5 species), rarely 8 (*C. flavus*). *C. korolkowii*, however, is exceptional in both distribution (Turkistan) and chromosome number ($2n = 20$); though sharing the other features of the group mentioned it may not be closely related.

No sharp line can be drawn between autumn and spring species. Flowering of different species ranges from September to April or May, and the autumnal species vary much in the time of production of their leaves. Some species, e.g. *C. speciosus* (figure 10) and *C. byzantinus* (figure 13), flower in the autumn and produce their leaves in spring; others, e.g. *C. medius* (figure 9), produce their leaves at the end of the flowering period. Others again, e.g. *C. asturicus* (figure 11), have the leaves

above ground but short. Finally, some species e.g. *C. longiflorus* (figure 12), have them fully developed.

Blue and yellow flowers are never found in the same species (with the possible exception of *C. chrysanthus*). White forms of blue-flowering species are frequent, of yellow-flowering species rare; some species are always white. Flower colour is sometimes more or less constant in a group of related species (e.g. the 'Aureus' or 'Imperati' group), but in such groups as the *Biflorus-chrysanthus* group, already discussed, it is very variable.

The general impression given by the genus is firstly of a few isolated species without close allies. Perhaps the most striking of these is *C. byzantinus* (figure 13). In this the members of the two perianth whorls are very different in size, the inner being much smaller and erect, so that the flower recalls an Iris. On this account it has been put in a separate genus *Crociris*, but hardly justifiably. Other unusual features of this plant are its purple style and stigmas, and its preference for shade.

Secondly, there are some well-defined groups, like the *biflorus-chrysanthus* alliance with annulate corm tunics and a group of two autumn species having similar corms (*C. speciosus* (figure 10) is one of the latter).

There remains a large number of species without any very striking characters. Many of these fall into rather ill-defined groups like the 'Imperati' group, which is connected by *C. dalmaticus* to such species as *C. sieberi* (figure 7); this has flowers similarly coloured on both sides, a yellow throat, and a strongly netted corm. Some species like *C. medius* (figure 9), though without any particularly unusual features, have no obvious relatives.

Chromosome studies have not so far helped very much in classification. Certain groups, such as the 'Aureus' group, are distinctive, but many species—some of them very distinct morphologically like *C. byzantinus*—have diploid numbers in the 20–26 range. No genetical work has been done on *Crocus*, and hybridization experiments might throw further light on the interrelationships. However, it seems impossible with the present information to get any picture of the probable evolution within the group nor to devise a really satisfactory classification.

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New techniques for the study of enzyme mechanisms

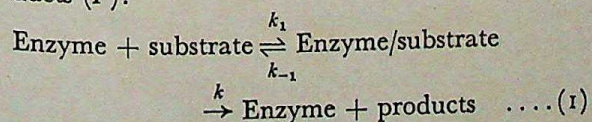
H. GUTFREUND

The importance of enzymes in regulating the complex system of chemical reactions which characterizes living cells needs no emphasis. Although the overall course of many enzyme-catalysed reactions is now well known, many details of the reaction mechanisms have still to be elucidated, and to do this new techniques have had to be evolved. These are of two principal types: methods for the identification of transient intermediates, and study of the kinetics of the reaction during the time, often extremely short, before a steady state is established.

INTRODUCTION

Enzymes are catalysts with a dual function in biochemical processes: by virtue of their specificity they select one of several possible reaction paths and they accelerate the rate of the chosen one without affecting the final equilibrium. All enzymes purified and characterized so far have been shown to be proteins. Some enzymes have a prosthetic group or coenzyme—such as haem or riboflavin derivatives—associated with the protein moiety, while others contain nothing but the amino acids of the protein structure. An understanding of the mechanisms of enzyme actions is essential to an understanding of how the complex biochemical processes of living cells are co-ordinated, and in recent years a number of important new techniques have been developed for the study of enzyme mechanisms.

One of the earliest and most fundamental concepts for the interpretation of enzyme-catalysed reactions was that developed by L. Michaelis and M. Menten [1]. They found that on increasing the concentration $[S]$ of the substrate—the substance on which an enzyme acts—the rate of an enzyme-catalysed reaction increases up to a constant maximum velocity $V_{\max}$, depending on the enzyme concentration $[E]$ and a constant k which depends on both the nature of the enzyme-substrate system and the physical conditions of the experiment. This relationship shows that compounds of enzyme and substrate (ES) are formed and that these then decompose into enzyme—thus made available for further reaction—and products (P):



By the Law of Mass Action the Michaelis constant K_m can be expressed as:

$$K_m = \frac{[E][S]}{[ES]} = \frac{k_{-1} + k}{k_1} \quad \dots (2)$$

From (1) and (2) it can be shown that the velocity V of the reaction can be expressed as:

$$V = \frac{d[P]}{dt} = \frac{k[E]_0[S]}{K_m + [S]}$$

where $[E]_0$ is the total concentration of enzyme, i.e. both free and combined with substrate. When $[S]$ is very large compared with K_m , all the enzyme is in the combined form, and

$$V = V_{\max} = k[E]_0$$

Under any given set of conditions K_m and $V_{\max}$ (and also k if the molar concentration of enzyme is known) are normally easily determined by plotting $1/V$ against $1/[S]$ and evaluating $V_{\max}$ at $[S] = \infty$ from extrapolation to $1/[S] = 0$.

The Michaelis constant can often be used as a measure of the specificity or affinity of an enzyme for various substrates. From equation (2) it can be seen that the relative magnitudes of k and k_1 decides whether K_m is a true equilibrium constant, and therefore a measure of the binding energy of substrate and enzyme, or whether it describes a transient state. One of the important results of new techniques to be described is that they enable us to ascertain for several enzyme systems whether or not K_m approximates to k_{-1}/k_1 .

The study of enzyme reactions has as its ultimate aim a complete chemical explanation of the interaction of substrate with enzyme and of the subsequent reaction sequence that results in regeneration of free enzyme and final products.

This involves first the identification of the active groups on the enzyme and secondly a study of reaction mechanisms. In the case of enzymes with prosthetic groups it is relatively easy to ascertain the catalytically active site; in the case of pure proteins, however, one normally has to draw conclusions from circumstantial evidence. The number of different reactive side chains in the amino acids which form protein molecules is not very large; they are usually known from chemical analysis, and they can be identified in any particular enzyme system by correlating their known reactivities and ion association constants with inhibition studies [2, 3].

Both for the identification of groups of enzymes and for the elucidation of the mechanism of the reactions between enzymes and substrates one has to study the overall reactions under a variety of conditions with a number of different substrates, and for this purpose to devise methods which will reveal details of the kinetics of the reaction. The reaction between an enzyme molecule and a complex substrate molecule proceeds by way of a number of kinetically distinguishable steps. The overall rate constant k may characterize one particular step if this is very much slower than any of the others. In many cases, however, two or more steps have rates of the same order of magnitude resulting in an overall rate defined by

$$\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \dots + \frac{1}{k_n} \quad \dots (3)$$

The rate constant k_1 of the formation of the initial enzyme-substrate compound is omitted from this relationship for the following reason. We can distinguish between the initial combination of enzyme and substrate, which follows second-order kinetics, depending on both enzyme and substrate concentrations, and all subsequent reactions of the enzyme-substrate compound, which follow first-order kinetics. This makes it possible to neglect k_1 when the substrate concentration is very high and, as will be shown, also to determine k_1 when the substrate concentration is very low. In many cases the overall rate constant of an enzyme reaction—and its dependence on pH, temperature, solvent composition, and modification of the substrate—does not characterize any one reaction step but is determined by two or more. In formulating reaction schemes for mechanisms and kinetic equations for the consecutive reactions, only such steps as have been experimentally distinguished should be taken into consideration.

Many very general schemes for the kinetics of

enzyme reactions taking place under varied conditions and with hypothetical mechanisms have been reviewed during the last few years. We shall here describe a variety of new techniques for following the rates of enzyme reactions continuously, without sampling and over periods ranging from a few milliseconds to several minutes: these techniques have proved useful for the identification of specific steps. Techniques for studying such fast reactions are needed because the initial combination between enzyme and substrate is very rapid, and any intermediate enzyme-substrate compounds are therefore very short-lived.

Two distinct methods have been developed for the study of intermediate steps in enzyme reactions. First there is the method of 'observable intermediates', originally applied by B. Chance [4] to a number of enzyme systems having prosthetic groups or coenzymes whose absorption spectra change at some specific stage of the reaction sequence. The same principle is involved in the study of reactions of pure-protein enzymes with substrates whose spectra change during the course of the reaction. A second method for the kinetic analysis of intermediate steps was recently developed by the author [5]; this involves study of the initial acceleration of the rate of formation of the final products of enzyme reactions. When the steady rate of enzyme reactions is measured over periods of minutes, all intermediates have reached their steady-state concentration by the time of the first measurement. If, however, measurements are taken during the first few milliseconds of the reaction, the rate of appearance of the observed product increases until the concentration of enzyme-substrate compound reaches this steady state. The rate of the initial enzyme-substrate combination, as well as the rate of formation of other intermediate enzyme-substrate compounds, can be calculated from equations derived [5] for a number of special cases of initial acceleration phenomena.

FAST-REACTION METHODS

Each of the fast-reaction techniques described here was originally developed to solve one particular problem. Although most of them have found wider applications, the principles involved are best illustrated by reference to the system for which they were originally devised.

Most techniques for studies of rapid reactions in solutions are based on developments of the continuous-flow methods of H. Hartridge and F. J. W. Roughton [6]. This procedure consists of passing

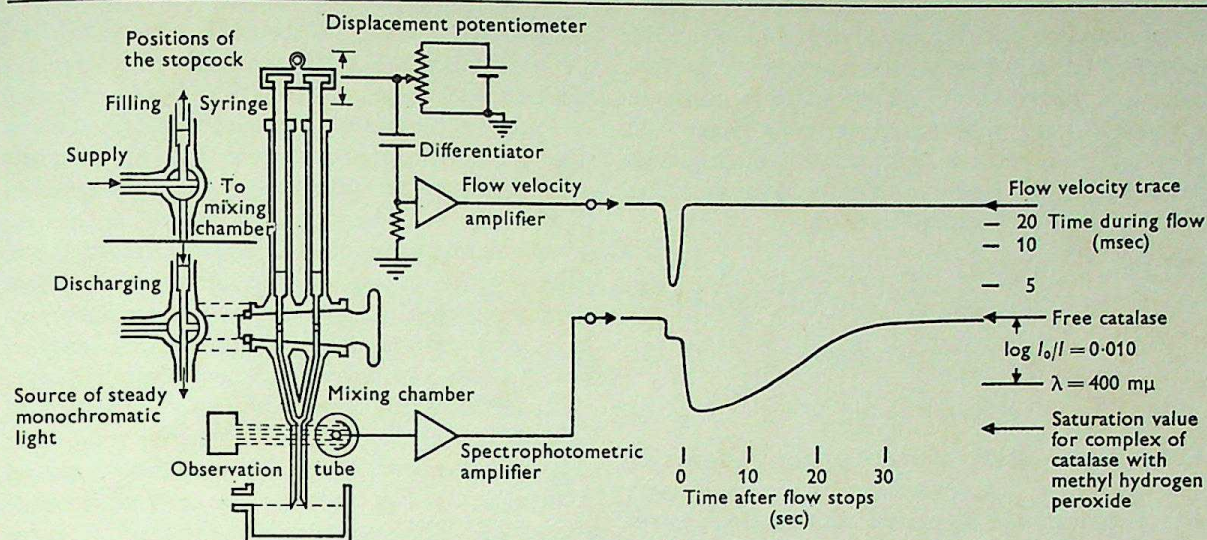


FIGURE 1 - Diagram of apparatus for the accelerated- and stopped-flow methods of studying fast chemical reactions. At the right are shown typical experimental data for the formation and decomposition, in the presence of ethanol, of the complex formed between catalase and methyl hydrogen peroxide. (After B. Chance [9].)

solutions of the two reactants, from separate containers, through a mixing chamber into an observation tube. If the flow of the mixed solutions in the observation tube is controlled at a known and steady rate, and the state of the reaction is observed in the tube at various distances from the mixing chamber, the reaction velocity can be calculated. The technique can be modified to meet particular circumstances by varying both the nature of the flow and the method of observation. So far as flow is concerned there are three major modifications:

1. Continuous-flow techniques, involving observations as described above.
2. Accelerated-flow techniques, involving observation at one point at varying flow speeds so that the time between mixing and reaching the point of observation is varied.
3. Stopped-flow techniques, involving observation in a chamber, immediately adjacent to the mixing chamber, after very rapid flow has been suddenly arrested.

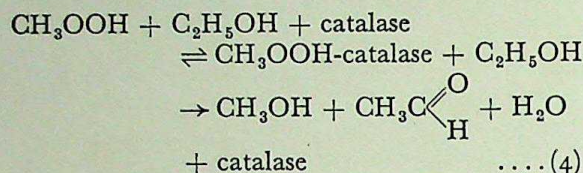
A number of methods of observation have been employed, choice depending on their suitability for giving a continuous and rapid record of changes in the concentrations of particular reactants or products. The methods most widely applicable are photometric (spectrophotometric and fluorometric); potentiometric (measurements of pH and oxidation-reduction); and thermal.

Continuous-flow techniques, first employed [6] for kinetic studies of various reactions of haemoglobin, are not generally suitable for observations on enzyme systems because of the large quantities of materials, of the order of a litre of solution of each reactant, needed. The accelerated- and stopped-flow techniques, however, enable one to carry out a whole investigation on a few millilitres of reactant solutions.

CHANCE'S ACCELERATED- AND STOPPED-FLOW METHODS

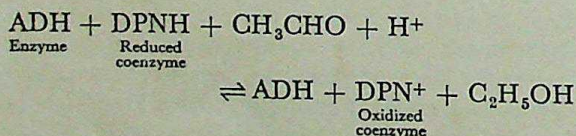
The spectrophotometric observation of the course of reactions in stopped-flow procedures has so far been the most useful method for the study of enzyme systems. The method involves driving the two reacting solutions from syringes into a mixing chamber and thence to the observation chamber; attached to the outflow from this chamber is a third syringe, the piston of which has just enough freedom of movement to allow a fraction of a millilitre to pass through the chamber before the flow of liquid is suddenly arrested. The degree of transmission of light of a selected wavelength is recorded when the flow of liquid has stopped. This procedure can give information about the change of concentration of reactants or products from 2 or 3 milliseconds after mixing. As originally designed by Chance (figure 1) the apparatus was used with a free outflow, without any stopping syringe: it could thus be used for combined accelerated- and stopped-flow experiments. The use of the method can be exemplified

by measurement of the rate of combination of the haemenzyme catalase with its substrate, methyl hydrogen peroxide, in the presence of ethanol. Although some side reactions take place, the principal products are methyl alcohol, acetaldehyde, and water, and to a first approximation the reaction can be described by:



Catalase has a strong absorption band at 4000 Å; this absorption is approximately halved when the enzyme-substrate compound with methyl hydrogen peroxide is formed. Figure 1 shows the flow velocity (as milliseconds elapsed between mixing and observation) and the change in light absorption: two phases of this record require separate interpretation. Firstly, during the period of accelerated flow, data can be obtained for calculating the rate of the rapid combination of catalase with peroxide to form the enzyme-substrate compound. Secondly, after flow was arrested, a phase of slower reaction is recorded; as the substrate is exhausted, progressively less enzyme is present in the combined form. From this second record further data about the enzyme-substrate dissociation constant can be evaluated. The kinetic equations and a wide range of experimental results have recently been reviewed [7].

An ingenious form of rapid-reaction spectrophotometry has been used by H. Theorell and B. Chance [8] to study some of the steps in the reactions of liver alcohol dehydrogenase (ADH). The course of this reaction can be followed by observation of the changes in the spectrum of the coenzyme diphosphopyridine nucleotide (DPN), which is required for the reaction:



The difficulty of measuring the small change in light absorption resulting from the formation of the enzyme-coenzyme complex (ADH-DPNH) and in that resulting from oxidation of DPNH to DPN⁺ was overcome in the following manner. The absorption of free DPNH is the same at both 3280 Å and 3540 Å, but the maximum change in molar extinction due to the addition of ADH

occurs near 3540 Å; furthermore, free DPNH and DPNH bound to ADH have identical molar extinction coefficients at 3280 Å. Chance [9] has designed an apparatus in which the light absorption can be measured at two or more wavelengths simultaneously: this is done by chopping each light beam at different frequencies. The output of the photocell is amplified in a circuit which can either record separately the changes in optical density at each wavelength or measure the difference of light absorption at two wavelengths. For the above investigation Theorell and Chance recorded the difference between light absorption at 3280 Å and 3540 Å, as well as the total light absorption at 3280 Å. In this way they obtained information about both the rate of formation of the ADH-DPNH complex and the rate of oxidation of DPNH to DPN⁺, enabling them to interpret the kinetics of this enzyme system.

The necessity for economy in the valuable biochemical preparations used required the design of small observation chambers with an optical path of 1–2 mm. Furthermore, to follow most enzyme reactions it is necessary to detect either very small changes in molar extinction in solutions of low enzyme concentration or equivalent changes in the molarity of the coenzyme or substrate. This demanded the development of very sensitive spectrophotometric equipment. Strong monochromatic light sources are often necessary to detect changes within a narrow absorption band. Sensitive photomultipliers and stable amplifying and recording equipment with rapid response are required to measure changes in the intensity of the transmitted light. Chance has developed these various components of flow spectrophotometers to the highest level so far achieved, and his apparatus is extremely versatile. For certain specialized purposes, however, a simpler stopped-flow apparatus designed by Q. H. Gibson [10] is proving very useful.

GIBSON'S STOPPED-FLOW APPARATUS

This apparatus was originally developed for studies of the initial rate of combination of haemoglobin with oxygen. In its present form it is suitable only for spectroscopic observation with visible light: filters are used to select the particular wavelength of light required to detect changes in the concentrations of reactants or products. An original feature of the apparatus is the piston used for suddenly arresting the flow of the reactants. This device decreases the stopping time to about 1 millisecond and thus permits the study

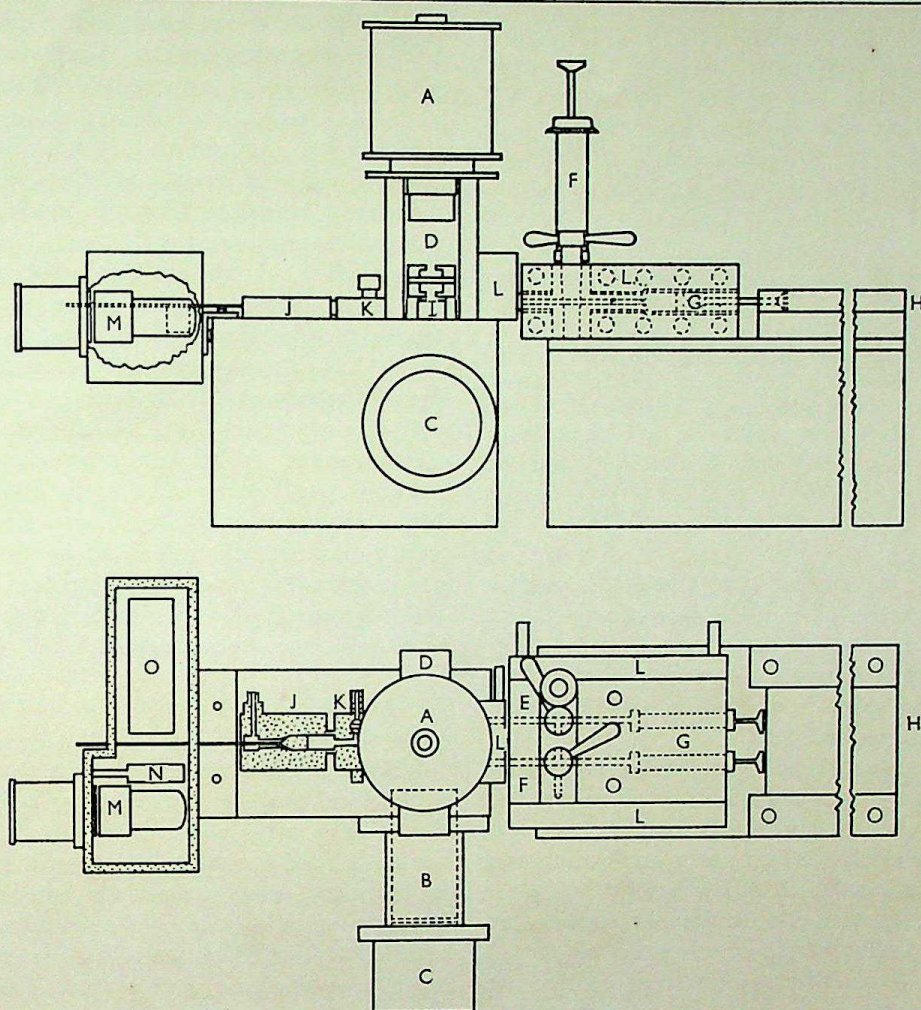


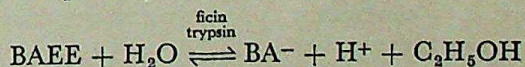
FIGURE 2 — Elevation and plan of stopped-flow apparatus, after Q. H. Gibson [10]. Key: A, lamphouse; B, C, photomultiplier and housing; D, filter carriers; E, F, 10 ml storage syringes; G, 2 ml syringes for driving solution from E and F into mixing chamber under lamphouse and filter carriers; H, block, running in V-guides, for driving pistons of syringes; I, mixing chamber; J, flow-stopping device; K, outflow tap; L, steel block through which water can be circulated to maintain constant temperature; M, N, O, apparatus for recording flow.

of reactions with half-lives ranging from about 2 milliseconds upwards. Figure 2 shows the whole equipment, with the exception of the cathode-ray oscilloscope that is used for recording changes in light absorption by measuring the output of the photomultiplier (B).

The author and his colleagues [5, 11] have made extensive use of the Gibson apparatus in a variety of studies on the mechanism of enzyme-catalysed hydrolyses. To study the initial accelerations of ester hydrolyses a method has been adapted [12] for following changes in H^+ ion concentration spectrophotometrically by the use of indicators. Nitrophenyl esters have been used as substrates for hydrolytic enzymes, and it has been found possible to distinguish spectroscopically between

different steps in the reactions between enzyme and substrate.

Figure 3 shows the record of measurements of changes in H^+ ion concentration during hydrolysis of benzoyl-L-arginine ethyl ester (BAEE) catalysed by trypsin or ficin in the presence of $10^{-3}M$ *p*-nitrophenol at pH 7.0:



In the reaction with trypsin the initial rate of formation of the enzyme-substrate compound is very rapid ($k_1 > 5 \times 10^6 M^{-1} \text{sec}^{-1}$), and even at very low substrate concentrations a steady state is reached within a few milliseconds. For the ficin-catalysed reaction the initial reaction is much

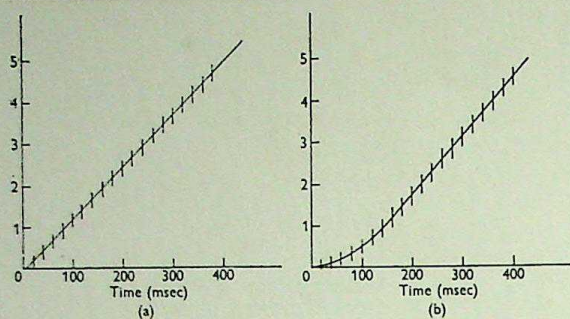


FIGURE 3 — Oscilloscope traces showing changes in indicator colour during initial phase of enzyme-catalysed ester hydrolysis. (a) Trypsin-catalysed hydrolysis of benzoyl-L-arginine ethyl ester (enzyme, 10^{-6} molar; substrate, 4×10^{-5} molar). (b) Ficin-catalysed hydrolysis of same ester (enzyme, 10^{-4} molar; substrate 10^{-2} molar). (From H. Gutfreund [5]). The ordinates represent optical density changes, in arbitrary units.

slower ($k_1 = 5 \times 10^2 \text{M}^{-1}\text{sec}^{-1}$), and it is possible to observe acceleration of the rate of appearance of products before the establishment of a steady state. Methods for evaluating rate constants from studies of the initial acceleration have been described in some detail [13].

The enzyme-catalysed hydrolysis of nitrophenyl esters (acetates or phosphates according to the enzyme) is a reaction very suitable for analysis of different steps in hydrolytic and transfer processes. H. Gutfreund and J. M. Sturtevant [11] followed the rate of liberation of nitrophenol and of acetate during the initial phase of reactions of chymotrypsin, and were able to show that a three-step mechanism is necessary, and sufficient, to explain experimental results observed with a large variety of substrates. For different substrates, however, either the second or third step or a combination of the two determines the rate. The first step is a rapid adsorption; the second involves formation of an enzyme-acyl compound, with concomitant liberation of the basic part of the substrate; and the third is hydrolysis of this enzyme-acyl compound. Experimental evidence indicates that the enzyme is acylated at a serine hydroxyl group that interacts with one of the imidazole groups on the enzyme surface. Similar methods are being applied by the author to a study of a number of enzyme-catalysed reactions.

THE FLUORESCENCE METHOD

H. Theorell and A. P. Nygaard [14] found that fluorescence measurements were up to a thousand times more sensitive than spectrophotometry for the study of some dissociation reactions of enzymes with coenzymes. When flavine mononucleotide be-

comes attached to protein to form yellow enzyme, the fluorescence disappears. The forward reaction ($k_1 \approx 10^5 \text{M}^{-1}\text{sec}^{-1}$) was found to be second-order, while the dissociation reaction ($k_{-1} \approx 10^{-3} \text{sec}^{-1}$) is first-order. Accurate constants were obtained under a wide variety of conditions, enabling deductions to be made about the mode of enzyme-coenzyme combination.

Theorell [15] also applied the fluorescence method to further studies of the alcohol dehydrogenase diphosphopyridine nucleotide system, which has already been mentioned (p. 220). DPNH fluoresces with the same intensity whether it is free or bound to ADH, but DPN does not fluoresce. With the fluorescence method Theorell could carry out experiments in very dilute solutions (10^{-6}M), and combination of such measurements with those obtained spectrophotometrically gave much further information about the sequence of events during the reversible reaction previously mentioned.

CALORIMETRIC STUDIES OF ENZYME REACTIONS

Since there is always some heat change during a chemical reaction, calorimetry is in principle the most general method for obtaining a continuous record for the calculation of kinetic data. Since many enzyme reactions are accompanied by changes in the state of ionization of the reactants, a suitable choice of buffers can result in large heat changes, and experiments using different buffers help to distinguish between ionic and non-ionic steps in the reaction.

Accurate thermal measurements on a number of enzyme-catalysed hydrolyses have been reported during the last few years by Sturtevant [16]. These were reactions with half-lives of a few minutes, and they were characteristic of the steady-state velocity only. Such measurements are of great value; apart from giving thermal information about the reaction, they give a continuous plot and are so sensitive that rate data can be obtained when the concentration of the substrate is apparently constant.

Rapid-reaction techniques using temperature changes to follow the rates of reactions with half-lives of much less than a minute have not so far been applied to enzyme systems. The continuous-flow thermal method which has so far proved successful is too costly in enzyme, and a stopped-flow calorimeter of sufficient sensitivity and rapidity to overcome this drawback is only now in course of development.

MISCELLANEOUS METHODS AND
FURTHER DEVELOPMENTS

Several other modifications of the rapid-reaction techniques described here have been developed, and although they have not yet been applied to studies of isolated enzyme reactions they are likely to prove useful for this purpose in the near future. Chance [17] has been able simultaneously to record a number of physical properties (spectrum, oxygen tension, pH) during respiratory processes in various biological systems, and has overcome difficulties presented by the measurement of small spectral shifts which occur during oxidation in cytochrome systems in turbid suspensions.

Gibson [18] has shown how flash photolysis can be used for the study of very rapid reactions between haemoglobin and oxygen or carbon monoxide. If a carboxyhaemoglobin solution is exposed to the light from a flash-discharge tube,

decomposition into haemoglobin and carbon monoxide occurs. The recombination of haemoglobin with either carbon monoxide or oxygen in the solution can be followed after the flash by conventional spectrophotometric methods. Chance [17] has employed photochemical initiation methods: such procedures permit the study of much faster reactions than can be investigated by the flow methods, since the limitation imposed by the finite rate of mixing of two solutions is removed.

So far as the future is concerned, the greatest advances in kinetic studies of reactions catalysed by isolated enzymes are likely to come from a combination of the methods described above. By observations at different wavelengths, and with instruments measuring different physical quantities, a single reaction can be investigated in several ways and the complex sequence of chemical events which comprise the reaction as a whole can be mapped out.

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High-temperature chemistry

G. PORTER

Reactions at high temperatures present many points of both theoretical and practical importance. This article is concerned with reactions at temperatures up to about 5000°C , above which, at ordinary pressures, molecular species disappear and matter consists almost wholly of atoms and ions. Among the problems discussed is that of the latent heat of sublimation of carbon, a physical constant of great importance whose accurate determination has been the most outstanding thermochemical achievement of the past ten years.

Despite developments in the field of nuclear engineering, chemical reactions are still the most important sources of high-temperature heat and hence of power. Since the efficiency of any heat engine is determined by the second law of thermodynamics and is proportional to the difference of the temperatures between which it works, increasing engine efficiency is, to a great extent, a matter of achieving higher and higher working temperatures. This is probably the most important reason for the present interest in high-temperature reactions, particularly in connection with the newer jet and rocket engines. Practical problems demand increased knowledge of the gaseous reactions in the fuel and of the behaviour of refractory solids at high temperatures.

There are other high-temperature chemical problems associated with high-speed flight. The shock wave ahead of a supersonic aircraft raises the temperature of the air behind the shock front; at Mach 4 the nose of an aeroplane would be heated to 1000°C if it were not cooled. At still higher speeds the temperature is sufficient to cause the nitrogen and oxygen to react to give oxides of nitrogen, and consequently allowance must be made in aerodynamical calculations for possible changes in the composition of the gas. The ultimate high-temperature problem of flight is the so-called re-entry problem; this is important when a long-range ballistic missile re-enters the atmosphere at high speed, when it is liable to vaporize before it reaches its destination.

Practical applications of high temperatures are not of course confined to those of flight. Chemical technology now utilizes temperatures around 2000°C for many purposes, and it is unlikely that materials will be found which will contain a reaction proceeding at much higher temperatures, in the sense that a furnace wall contains the reacting material. But this does not preclude the utilization of higher temperatures for chemical

transformations; indeed, they are familiar in electric arcs and in some flames where there is either no container at all or its temperature is far below that of the reaction zone. So far as chemistry is concerned with molecules we can probably set an upper limit of about 5000°C ; above this, at normal pressures, all matter is gaseous and is composed essentially of atoms and ions. At such temperatures all reactions in the gaseous phase are extremely fast, and it is doubtful whether much will be gained by going to greater temperatures than those used at present. This is not, however, true of condensed systems, in which very useful transformations—particularly phase transformations—may be effected at high temperatures and pressures. The most striking example of this is the conversion of graphite to diamond in an apparatus capable of sustaining temperatures of about 3000°C at pressures of $100\,000\text{ kg/cm}^2$ for periods of the order of minutes [1]. There are many possibilities for the synthesis of new materials in this way: for example, several new forms of silica have recently been produced [2].

At temperatures above 5000°C matter becomes an ionized plasma, the study of which is the concern of the rapidly developing sciences of electro- and magnetohydrodynamics, and at a few million degrees centigrade we enter the range of thermonuclear reactions. Neither of these are within the province of chemistry—at least as defined for the present article.

The main problems of high-temperature chemistry are as follows. Firstly, there are the practical problems of producing high temperatures by chemical means. Secondly, we have to discover the nature of the substances that are stable at high temperatures and the equilibrium relations between them. Finally, we must study the rates of reactions at high temperatures, since they may determine the rates of flame propagation and similar phenomena. These are the problems

which confront a chemist in many fields, but at very high temperatures special difficulties arise. Special techniques must be devised, and there are particular theoretical problems to be solved, especially those concerned with the measurement of temperature in a rapidly changing system.

HIGH TEMPERATURES FROM CHEMICAL REACTIONS

The conversion of chemical energy into high-temperature heat still provides one of the most convenient methods of attaining high temperatures. If the reaction proceeds adiabatically, the temperature rise at the end of reaction is simply the heat of reaction at the initial temperature divided by the integrated heat capacity of the products between the two temperatures.

The ordinary Bunsen burner reaches a temperature, just above the reaction zone, of 1800°C : this is very close to the value calculated in the above way on the assumption that water and carbon dioxide are the final products of reaction. A stoichiometric methane-oxygen flame reaches 2700°C , but if calculated on the basis of the same substances being the products of combustion, it would attain 5000°C . The discrepancy is caused by the fact that, even at equilibrium, the burnt gases are highly dissociated into CO , H_2 , and O_2 , as well as into free radicals and atoms such as OH , O and H . In fact, the free radical OH forms 14 per cent of the total products of this flame just above the reaction zone. This dissociation uses up a large part of the heat of reaction, and so limits the flame temperature that its final value is determined only to a limited extent by the enthalpy (heat content) change, and the nature of the high-temperature equilibrium products is a very important factor. An interesting example of this is the cyanogen-oxygen flame, which burns to form CO and N_2 . Neither of these molecules dissociates appreciably below 3700°C , and although the heat of reaction is quite moderate the mixture gives the hottest flame known and attains very nearly the theoretical temperature of 4600°C . Other very hot flames—for example, fluorine and hydrogen (4500°C), aluminium and oxygen (3500°C), and beryllium and oxygen (4500°C)—also have very stable reaction products.

These temperatures are high enough to melt any known solid, and are probably near the limit of what can be achieved with conventional fuels. The use of ozone in place of oxygen will give a greater heat of reaction and a higher temperature,

but to get still higher temperatures we should probably have to use fuels which were themselves already largely dissociated into atoms—oxygen atoms, for example. This does not appear to be a very promising line of approach, but it would be imprudent to dismiss it as quite impracticable. Firstly, there is a source of oxygen atoms in the upper atmosphere, just where it might be useful for rocket flight: about 80 miles above the earth the photostationary concentration of oxygen atoms exceeds that of oxygen molecules, although unfortunately the concentration of both is very low. Secondly, methods of stabilizing atoms and reactive free radicals by freezing them into a matrix at low temperatures have recently been developed [3], and the storage of bulk quantities may not be out of the question. This possibility is at present being actively studied.

CHEMICAL EQUILIBRIA AT HIGH TEMPERATURES

For the study of equilibria, the furnace may be used for temperatures up to about 1700°C ; flames, in which the gases above the reaction zone are essentially at equilibrium, may be used for higher temperatures. The present emphasis in research is on the identification of the principal species which exist in high-temperature equilibrium systems of gases, but even this subject is not far advanced. The methods of detection which are being found most useful are optical spectroscopy, mass spectrometry, and radio-frequency spectroscopy.

It has long been known, from spectroscopic evidence, that many substances are present in hot gases which are never present in detectable amounts at lower temperatures. For example, the green colour of the cone of the flame formed when natural gas burns in air is due mainly to emission by the C_2 molecule, but OH and CN can also usually be detected. By introducing various additives into the flame, either as gases or in solution as sprays, a wide variety of other species can be studied spectroscopically at high temperatures. The temperature of the flame can be altered by changing the proportions of the mixture, and a study of how the composition varies with temperature makes it possible to estimate thermochemical constants. There is appreciable ionization in the flame gases, and the electron concentrations can be measured by radio-frequency techniques; by measuring the change in concentration with temperature, thermochemical data concerning ionic species can be deduced. In this way, for

example, the electron affinity of the OH radical has been measured [4].

Some of the most interesting work on high-temperature equilibria is that concerned with the gaseous species that are in equilibrium above solids having high melting points, particularly inorganic oxides and salts. These species are often very numerous and sometimes rather unexpected. For example, above barium oxide the gaseous molecules Ba_2O , Ba_2O_2 , BaO , and Ba_2O_3 have been observed [5], and all the alkali hydroxides appear as stable gaseous molecules. L. Brewer [6] has found that, in the gas phase, cuprous chloride exists mainly in the form of the triple polymer $(\text{CuCl})_3$, which has been shown to have a puckered-ring structure.

One example must suffice to illustrate some of the difficulties of quantitative thermochemistry at high temperatures. The example is a particularly important one—the determination of the latent heat of sublimation of carbon, or the energy required to separate one gram of carbon atoms from graphite. The standard method of determining such a quantity is to measure the vapour pressure of the material over a range of temperatures and to apply the Clausius-Clapeyron equation. In the case of carbon, however, where the sublimation pressures at workable temperatures are very small, the most convenient procedure is to measure the rate of effusion of carbon vapour through a small hole of known size in a furnace containing solid carbon at a high temperature. This experiment has been performed many times, in a number of laboratories, but with widely differing results. Published values for the latent heat of sublimation have ranged between 110 and 190 kcal/gram atom, and even two or three years ago the correct value was a matter for speculation. A different method of measurement, based on spectroscopic determinations of the dissociation energy of molecules such as carbon monoxide, served only to make the problem more intriguing, for they gave a number of apparently very accurate values for the latent heat covering as wide a range as those given by the thermal methods. It was, however, known that only one of these values could be correct, so that no more than a reasonably accurate measurement by some other method would be sufficient to decide which was right.

One of the main troubles of deducing the latent heat of sublimation from vapour pressure measurements was that most substances are more volatile than carbon, so that impurities, even in minute amounts, could invalidate the results. In the

effusion method there were troubles concerned with the size of the hole through which the vapour effused: the hole has to be large enough to allow the experiment to be completed in a reasonable time, yet small enough to ensure that true solid-vapour equilibrium is established. Perhaps the most serious difficulty is one that was not really appreciated until relatively late in the history of the problem—that the particles leaving the carbon surface might not all be single atoms, so that the measured latent heat refers to equilibrium with some gaseous species other than carbon atoms. It was known that the diatomic molecule C_2 was stable, but there was good evidence that the contribution made by this molecule was small. Only very recently had C_3 been discovered spectroscopically, and there was no reason to suppose that this molecule was of any importance in the vapour at equilibrium.

The problem was ultimately solved by the mass spectrograph, and it seems certain that this instrument will in future play a predominant part in research on high-temperature equilibria. It overcomes all the difficulties mentioned above, since very small amounts of gas can be estimated and each species can be separately identified. When the technique was applied to the problem of the latent heat of sublimation of carbon by W. A. Chupka and M. G. Inghram [7] and by R. E. Honig [8] the problem was seen to be more complex than had previously been apparent. Not only was C_2 found to be an important constituent of the vapour in addition to C and C_2 , but C_5 was also present; in addition there were appreciable amounts of negative carbon ions ranging from C^- to C_8^- . Study of the variation of the relative amounts of these species with temperature led to the evaluation of their heats of formation as well as to the latent heat of sublimation of carbon to atoms, L_c . Subsequent work has confirmed these experiments and established the value of L_c at 25°C as 170.89 ± 0.5 kcal/gram atom, thus resolving the outstanding thermochemical problem of the decade.

HIGH-TEMPERATURE KINETICS

The study of high-temperature kinetics is necessarily the study of fast reactions, although the converse is not true, because very many reactions are extremely fast at normal temperatures. The rate of a reaction is usually well represented by the equation

$$\text{Rate} = Ae^{-E/RT}$$

when E is an energy of activation, R is the gas constant, and A is a frequency factor which varies little with temperature. As the temperature is raised, the frequency factor assumes increasing importance relative to the activation-energy term. As the rate increases, there comes a point where we can no longer discuss the mechanism in these familiar terms, which are based on the concept of an equilibrium distribution of energy between the various motions of the molecules, because the rate of transfer of energy itself becomes important. The study of very fast reactions and of energy transfer are therefore two aspects of reaction kinetics which become particularly significant at high temperatures; in addition, the properties of electronically excited states may become important.

Experimentally, the outstanding problem to be faced is that of raising the temperature of the system quickly enough to make significant rate measurements possible. If this can be done, a study of the reaction is usually possible by modern electronic techniques, even if the time of reaction is only a few microseconds. But if the reaction itself is of such short duration it is obviously essential that the temperature rise be brought about in an even shorter interval of time; moreover, this must be done homogeneously throughout the material being investigated. Suppose, for example, that we wish to study the kinetics of thermal decomposition of ethane into ethylene and hydrogen at 1500°C , at which temperature the half-time of decomposition is one-millionth of a second. At 1000°C the half-time of reaction is one three-hundredth of a second, so that if we remain at 1000°C for as long as this, most of our material will have reacted before the experiment at 1500°C even begins. The method which is usually applied to slower gas reactions—that of admitting the gases to a vessel heated to the required temperature—would be quite useless for an experiment of this kind, since the observed rate of decomposition would be determined by the rate of thermal diffusion rather than by that of chemical reaction. Flow methods are sometimes useful, particularly in the study of flames, but the interpretation of such systems is rarely possible because of the complex diffusion phenomena associated with them.

The problem therefore resolves itself into one of raising the temperature of the gas, independently of its container, very rapidly and homogeneously. Two main methods fulfil these conditions—rapid adiabatic compression, particularly the extreme form of this, in which shock waves are utilized, and irradiation, the most useful form

of which is a short flash of visible or ultra-violet light. The electric arc is also a powerful and very simple method, but it is less useful for kinetic studies because of the uneven distribution of temperature within it.

Shock waves have been applied only very recently in investigating chemical problems. The principle is simple. When a gas is suddenly compressed it gains some heat; if the pressure is applied very rapidly, as may happen in an explosion, a high proportion of the mechanical energy is converted into heat. In the laboratory the shock can be produced in a very simple manner by bursting a diaphragm separating two parts of a tube containing gases at very different pressures. Temperatures of many thousands of degrees centigrade can be so attained, and, equally important, they can be produced quite uniformly throughout the gas in an extremely short time. The shock front is very sharp, because it heats the gas and so increases the velocity of sound in the gas behind it; the result is that the wave tends to pile up on itself, giving a shock front only a few molecules thick. Furthermore, the speed of the shock front may be so great that it passes two slits, one millimetre apart, in about one microsecond. If, by some optical method, we examine the gas as the shock front passes, it is quite possible to heat the gas to several thousand degrees and begin measurements of reactions in it within the space of a few microseconds.

The shock tube has so far been applied only to a few chemical kinetic problems, the main ones being the dissociation of nitrogen oxides [9] and of halogen molecules into atoms [9, 10]. The latter study was exceptional in kinetic work because the rate constant can also be derived from flash photolysis studies of the reverse (recombination) reaction at low temperatures. The two methods provide an expression for the rate constant of dissociation of bromine over a temperature range corresponding to a change in the rate by a factor of 10^{27} . The shock technique promises to be one of the most powerful methods for the study of high-temperature gas kinetics.

The second method for producing a rapid temperature rise utilizes the energy of a light flash of a few microseconds' duration, and has not yet been fully investigated specifically for high-temperature research. It has been much used for producing rapid dissociation or electronic excitation [11], but in these applications one is usually concerned with keeping the system nearly isothermal, which can be accomplished by working

with excess of inert gas. The course of the subsequent reactions is, as usual, studied by optical and electronic methods. If the inert gas is omitted and the substance is an efficient absorber of light, a very rapid temperature rise results, because all the absorbed energy that is not used in chemical reactions will be dissipated as heat. Energies of the order of 100 kcal/mole may be absorbed, and the corresponding temperature rise may be very considerable: for example, if the specific heat of the gas remained constant at 5 cal/mole, a temperature of about 20 000° C would be attained. As usual, the gas dissociation greatly reduces this temperature, but in the first stages the rate of heating is nevertheless very high. The method has the disadvantage that it is restricted to gases which absorb light and that most of these—though not all—dissociate photochemically. It has the advantage, however, that the temperature rise may be produced fairly homogeneously in a long path of gas; reaction vessels one metre long are commonly used, and consequently absorption spectra have been observed of intermediates that cannot be detected by other methods. The main application of flash-radiation heating has so far been to the homogeneous initiation of explosion; in this case a long reaction zone has the advantage of making possible the detection and estimation of the intermediates as a function of time during the explosive reaction. It has been applied to high-temperature kinetic problems of practical importance, such as the mechanisms of carbon formation and of anti-knock action in internal combustion engines.

'TEMPERATURE' IN FAST REACTIONS

Some of the most interesting problems in fast-reaction kinetics are associated with the fact that the temperature itself cannot always be clearly defined. In a slower reaction, even though the gases are not in chemical equilibrium, the molecules are in thermal equilibrium with each other, and the energy is distributed among the various degrees of freedom in a well-defined manner. This Boltzmann distribution of energy forms the basis of all the usual formulations of theories of reaction rate.

In a typical fast reaction—such as the combustion reaction in a flame—the gases are heated, undergo a most complex series of chemical

changes, and leave the reaction zone as burned gases in a time which may be less than one-thousandth of a second. In such circumstances it is not surprising if thermal equilibrium no longer obtains at all stages of reaction. The absence of thermal equilibrium is shown most clearly when the 'temperature' of the reaction zone is measured by different methods. All the methods agree fairly well when applied to the burned gases above the reaction zone, but they may differ widely in respect of the reaction zone itself. If a method is used that depends on the degree of electronic excitation—as, for example, does the commonly used sodium line reversal method—we may find that the measured temperature depends not only on the element used but even on its particular electronic levels. Measured values as high as 8000° C have been found, using the reversal of iron lines, in flames whose theoretical maximum temperature was only 1700° C. Matters are little better when the temperatures associated with other degrees of freedom are measured. The 'rotational temperature', estimated from the intensity distribution among rotational lines in molecules like OH and C₂, may be as high as 10 000° C, and anomalies are also found in vibrational intensities. Even 'translational temperatures', which might reasonably be considered as true temperatures, seem to be anomalously high in some cases when measured from the Doppler width of spectral lines. Some flames, for example those of H₂ and CO, do not show any great anomalies, while others, for example hydrocarbon flames, show very large ones [12].

The anomalies are almost certainly caused by a breakdown of the Maxwell-Boltzmann distribution in rapidly reacting gases, and are to be expected fairly generally throughout high-temperature kinetics. The difference in temperatures determined by various methods tells us, in no uncertain manner, that simple rate-equations containing a single energy term and a single temperature value are not going to be sufficient. The problems of energy transfer between molecules and their various degrees of freedom, and of reactivity of molecules as a function not only of energy content but of its distribution within the molecule, present a field of general theoretical importance which is particularly relevant to high-temperature reactions.

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Towards a unity of knowledge

The editorial in our April issue, urging the need for a synthesis of scientific and humane studies, has been favourably received and widely quoted. The interest of those whose primary concern is with the humanities is particularly welcome, and for this reason we are glad to publish the following joint letter from Lord Samuel, Lord Halsbury, and Sir David Ross.

Sir,

We have been greatly interested to read the editorial article in your April number entitled 'Towards a unity of knowledge'. This impressive plea for a closer association between science and the humanities, appearing in a periodical with the status and influence of ENDEAVOUR, was very welcome to an organization such as The Royal Institute of Philosophy, one of whose chief objects is to try to bring philosophy into closer relation with the main currents of practical life. The point closely touches the present discussion of the right lines for the development of the national system of education in Britain.

The philosophers who in the latter part of the 17th century founded the Royal Society were soon obliged, by the rapid accumulation of knowledge about Nature, to departmentalize their work. In later generations they took the new name of scientist and separated their studies from the older branches of philosophy—metaphysics, ethics, and logic. This divergence has since continually widened, until we have become aware in the present generation of a gap, causing a lack of understanding and of any effective measure of association, that is having harmful results, not only in the sphere of education but also in ethics and in politics, both national and international.

But, as you say, 'it does not seem that the gap is unbridgeable'. Within science itself, you point out, a process of unification is going on that might have

seemed difficult a few decades ago, between pure and applied science, and again between physics and chemistry on the one hand and biology on the other. You suggest that, without either side sacrificing the specialization that is essential to efficiency, a synthesis might also be achieved, at a deeper level, between science itself and the humanities.

This is also our conviction. There is a wide province where the two overlap, particularly in theoretical physics and empirical philosophy, that is of great interest at the present time. And in general, in the universities and at all levels of education, it is becoming increasingly plain that science and philosophy cannot continue to go on regardless of each other's activities, sometimes, it would seem, hardly on speaking terms with one another. Every philosopher should understand the outlook and the conclusions of science, every scientist have an appreciation of the humanities; and every well educated man, while tending no doubt to a greater interest in the one or the other, should have had the opportunity to gain some knowledge of both.

When, therefore, you give prominence to such a plea, and show that from the side of science there is now a marked trend towards such a synthesis, we think it is right not to leave this initiative without response from the side of philosophy, but to say that a similar approximation is also to be seen among many present-day philosophers, and that there is reason to hope that it will continue and develop.

SAMUEL

President

HALSBURY

Vice-President

W. D. ROSS

Chairman of the Council

*The Royal Institute
of Philosophy
London*

Book reviews

THE EARTH AND THE HEAVENS
Encyclopédie Française. Vol. III, Le ciel et la terre, edited by A. Danjon, P. Pruvost, J. Blache. Pp. 452. Librairie Larousse, Paris. 1956. Fcs. 7450 net.

This work, to which 36 authors, all of whom are specialists in their subjects, have contributed, is divided into two parts, as indicated by its title. The first part comprises four sections dealing respectively with the solar system, the Sun and stars, the galaxies, and problems of evolution. The second and larger part is concerned solely with the Earth, considered from different aspects. The first section of this latter part deals with the problems of geophysics: meteorology, the aurora and airglow, the ionosphere, geomagnetism, tides, gravimetry and isostasy, seismology, and the interior of the Earth. The second section is geological and discusses the origin of the surface rocks, the transformations they have undergone, past geological history, and the information that can be derived about the evolution of the Earth. The third section is concerned with the Earth as it exists at present; its atmosphere and climates, the oceans, lakes, rivers and underground waters, and the moulding of the surface features.

The aim throughout the work has been to emphasize recent advances in knowledge and to present current theories and ideas, relating them to facts and theories that have been well established and are generally accepted, but without any detailed exposition. The volume therefore forms a valuable work of reference. The binding is in the loose-leaf form so that revised or new pages can be inserted; it is proposed to issue such pages from time to time, as new material becomes available. The illustrations are excellent and well selected; the large majority of those in the first part are reproduced from photographs obtained at French observatories.

H. SPENCER JONES

WAVE MECHANICS

Mathematics and Wave Mechanics, by R. H. Atkin. Pp. xv + 348. William Heinemann Ltd., London. 1957. 30s. net.

Mr Atkin has written this book for Honours degree students in physics and chemistry, and it is clear that he is a mathematician thoroughly familiar with their needs. The scope is wider than the title might suggest, for not only are many aspects of the application of wave

mechanics treated but some 200 pages cover most of the mathematical operations necessary in theoretical physics and chemistry.

The introductory chapters dealing with the more elementary concepts such as complex number theory and the evaluation of integrals tend inevitably to be unrelated, but this enables individual topics to be read with the minimum of reference to earlier pages. The purely mathematical chapters are concise and the worked examples included in the text are well chosen to illustrate and enlarge the theory.

The application of mathematics to physics is introduced by way of classical mechanics and electromagnetic theory. The results of experiments in the early twentieth century are then shown to give rise to special relativity and quantum mechanics. By this stage the reader should have become well acquainted with vector and matrix algebra. Numerous applications of wave mechanics range from the simple harmonic oscillator to Rutherford and Compton scattering, and there is a chapter devoted mainly to valency bonds.

The book is well produced and its price reasonable. W. R. MYERS

HYGROMETRY

Hygrometry, by H. Spencer-Gregory and E. Rourke. Pp. xv + 254. Crosby Lockwood & Son Ltd., London. 1957. 36s. net.

Humidity measurement is a factor of major importance in many industries, but the literature on the subject is widely scattered and there has been a need for a practical text-book for users of hygrometers. This book scarcely meets this need, since its emphasis is on detailed theory rather than on practical instruction.

The lay-out is rather muddled; for example, the introductory chapter occupies nearly one quarter of the book and includes much that would be more appropriate under the headings of the later chapters. There is, in consequence, frequent cross-referencing which could have been avoided by more careful planning.

Among the more useful chapters are those on the hair hygrometer and on the moisture content of highly compressed permanent gases. Another chapter gives psychrometer theory in great detail, but makes no mention of the recent work of J. L. Monteith. The

effect of lag in hygrometers is discussed, but its practical application is not made very clear.

The book may have some academic interest, but the technologist seeking practical guidance will probably be disappointed, especially on finding that only about half the authors quoted are included in the bibliography.

F. J. SCRASE

TENSORS APPLIED TO CRYSTALS

Physical Properties of Crystals, by J. F. Nye. Pp. xv + 322. Oxford University Press, London. 1957. 50s. net.

Many properties of crystals may be represented mathematically by tensors, though some, such as surface properties, cannot. Although not concerned to explain particular crystal properties in terms of structure, this work will be of great help to those interested in the attempt to do so. Its backbone is a treatment of tensors which shows how they may be used as a common basis for interpreting many properties and the thermodynamic relations between them.

The mathematical treatment is reasonably simple, but the work is likely to make its greatest appeal to post-graduate students and research workers. Metallurgists, and those engaged in solid-state physics, will find a useful introduction to tensors and matrix algebra. A number of properties, thermal, electrical, mechanical, are treated individually, and a special chapter gives a unified treatment of the thermodynamics of these equilibrium properties. Transport properties are dealt with separately. Crystal optics includes happily a section on optical activity in crystals.

H. M. POWELL

ORGANIC STRUCTURE

Introduction to Structure in Organic Chemistry, by C. K. Ingold. Pp. vii + 200. G. Bell & Sons Ltd., London. 1956. 20s. net.

In response to requests, Professor Ingold has reproduced, under the above title, the first four chapters of his larger treatise 'Structure and Mechanism in Organic Chemistry' which has now become a standard work of reference in the realm of physical organic chemistry. The four chapters of the present book are so comprehensive that they can hardly be considered as a mere 'introduction' to the subject.

The approach is essentially that of an organic chemist who needs to know about molecular structure in order to develop theories about chemical reactions. Thus after a short, fairly standard, introduction Ingold deals in his second chapter with interactions within and between molecules in terms of molecular polarization and molecular polarizability. This leads to a detailed explanation of the significance of inductive and mesomeric effects. The third chapter relates these concepts to physical measurements with aliphatic compounds and the fourth deals with aromatic character.

The book leaves one with a picture of tangible molecules of fairly definite geometrical shape with reasonably stable, though deformable, electronic constitutions. The picture is elucidated by experimental measurements and not just deduced by mathematical theory.

This treatment is just what the chemist requires and can comprehend.

W. A. WATERS

HETEROCYCLIC COMPOUNDS

Heterocyclic Compounds, Vol. V, edited by Robert C. Elderfield. Pp. vi + 744. John Wiley & Sons Inc., New York; Chapman and Hall Ltd., London. 1957. 160s. net.

This substantial book continues the high tradition of earlier volumes in this very valuable series. The eight chapters cover 1,3-dioxolane and derivatives (R. C. Elderfield and F. W. Short), pyrazoles and related compounds (T. L. Jacobs), indazoles (R. C. Elderfield), imidazoles and condensed imidazoles (E. S. Schipper and A. R. Day), oxazole and its derivatives (J. W. Cornforth), benzoxazoles and related systems (J. W. Cornforth), isoxazoles (R. A. Barnes), thiazoles and benzthiazoles (J. M. Sprague and A. H. Land). It is claimed that the major English and German-language periodicals have been covered up to the end of 1955. The pyrazoles (117 pages), the imidazoles (104 pages), the oxazoles (120 pages), and the thiazoles (239 pages) receive extremely full treatment.

It is a tribute to the uniformly high quality of the writing that these detailed and comprehensive chapters, though likely to be used mainly for reference purposes, are yet readable and stimulating. The generous use of formulae and the many footnote references (about 4000) make this book invaluable to the research worker. The formulae are occasionally awkward and there are

some errors; use should have been made of the simplifying Me and Et for functional methyl and ethyl groups and of Ph for phenyl. There are occasional unacceptable uses of arrow symbols. The cleavage of methylenedioxy groups by phosphorus pentachloride, followed by hydrolysis, is due to Barger (1908), rather than to German patents of 1915 and 1922. There is regrettably no author index, but the subject index is more comprehensive than those of the earlier volumes. W. BAKER

PETROCHEMICALS

The Chemistry of Petrochemicals, by Marvin J. Astle. Pp. v + 267. Reinhold Publishing Corporation, New York; Chapman and Hall Ltd., London. 1956. 52s. net.

During the last two decades a revolution has occurred in the manufacture of organic chemicals, in that petroleum has taken first place among the sources of carbon compounds. The rate of increase is itself increasing and it is impossible to predict the point of equilibrium between supply and demand in the foreseeable future. Major products are a wide range of solvents, glycol for antifreeze, detergents, agricultural chemicals of various types, and a long series of resins, plastics, and elastomers. We may expect, and must welcome, a series of books on the topic of petrochemicals to keep pace with such a rapidly expanding subject.

The author of the present work has had detailed experience in the industry and is at the present time Professor of Chemistry at the Case Institute of Technology, Cleveland. He is thus unusually well qualified to speak with authority on both the theoretical and practical aspects.

The book covers the material remarkably well and has some claim to be regarded as a work of reference. Nevertheless there are some noticeable gaps, one example being the omission of any mention of the important insecticides made from cyclopentadiene and its hexachloro-derivative. A good balance is maintained between the theoretical explanations and the summaries of actual conditions of reactions, this being a very valuable feature.

A high standard of accuracy is maintained but there are nevertheless a few fallings from grace. The spark that lit the polyethylene train was not an attempt to combine ethylene with benzene (p. 102) but with benzaldehyde. In the same section the emphasis in the description of the Ziegler catalyst is

wrongly distributed or there is misunderstanding; in either event it gives a wrong impression.

Though not perfect the book can be recommended both to students and to research workers in the field. The printing and presentation are good but the price is too high. R. ROBINSON

BIOCHEMICAL VARIATION

Biochemical Individuality, by R. J. Williams. Pp. xiii + 214. John Wiley & Sons Inc., New York; Chapman and Hall Ltd., London. 1956. 46s. net.

The genotrophic principle, as the author conceives it, is a broad one encompassing the whole of biology. It is stated that every individual organism possessing a distinctive genetic background has distinctive nutritional needs which must be fulfilled for optimal well-being. At the human level, the concept, even if true, is of little importance unless large variations in body chemistry can be demonstrated. This book gives a clear and concise account of these variations with reference, for example, to specific enzyme levels, endocrine activities, and nutritional needs. The reviewer is unaware of any similar attempt to bring together the available material on normal biochemical variation. The author outlines a substantial case in support of his conclusion that each human being possesses a highly distinctive body chemistry.

The author is convinced of the substantial truth of his general thesis but presents his ideas without dogmatism. The reader will find much that is original and the account is stimulating throughout. The ideas outlined have implications not only for biochemists and medical scientists but also for psychologists, anthropologists, and workers in the educational field.

The material is well arranged and printing, paper, and binding are excellent. W. G. OVEREND

VIRUS SYMPOSIUM

The Nature of Viruses (Ciba Foundation Symposium), edited by G. E. W. Wolstenholme and E. C. P. Miller. Pp. xii + 292. J. and A. Churchill Ltd., London. 1957. 42s. net.

This Symposium was held in March 1955 with the title of 'The Biophysics and Biochemistry of Viruses' under the chairmanship of Sir Charles Harington. Many of the world's leading virologists took part and the informal discussions following each paper constitute one of

the important features of the book. The subjects dealt with are the fundamental aspects of virology and include, among others, the structure of virus particles, chemical studies, multiplication of viruses, and studies of cell infections by means of fluorescent antibody and the use of radioactive influenza virus.

The study of virology now embraces so many widely differing disciplines that one welcomes this opportunity for physiologists and chemists to confer with biologists and so come to a closer understanding. Some of the results of the intensive research on the problem of virus during the last ten years are seen in this book. Crick and Watson discuss the general principles of virus structure with particular reference to the small plant viruses containing only protein and ribonucleic acid. This is followed by an interesting discussion by Robley C. Williams of the structure and sub-structure of viruses as seen under the electron microscope. This instrument alone is able to furnish morphological information about the individual virus particles by direct optical imagery. This discussion and the following one by Dr Franklin and her colleagues on X-ray diffraction studies, deal mostly with the structure of the tobacco mosaic virus particle. The work in California suggests that the ribonucleic acid (RNA) alone of the tobacco mosaic virus is infectious and raises the possibility of injecting RNA and DNA (deoxyribonucleic acid) directly into the cell to find out if these alone can start infection. Some of the practical results arising from this fundamental work on viruses are considered by Burnet in the general discussion. The purification of viruses may help in the production of vaccines to prevent virus infections in man. Furthermore, the most efficient vaccines are those with active avirulent strains of virus, rather than those with inactivated virus, and this work will help in the selection of suitable strains for this purpose.

Of two other major objectives one is the exploitation of the virus, as a comparatively simple system, in the understanding of protein synthesis. The other is the explanation of virulence, since this has a fundamental bearing upon the effects of the virus on the host. This was a most successful symposium and the book resulting from it is stimulating.

K. M. SMITH

MITOCHONDRIA

Symposia of the Society for Experimental Biology. No. X: Mitochondria

and other Cytoplasmic Inclusions. Pp. 198. Cambridge University Press, London. 1957. 55s. net.

This series of papers reflects the worries and confusion that are the lot of those who work in the fascinating field of the optical and chemical properties of cell components. This is most marked in the case of the Golgi 'zone' or material, where alternate authors assert that it is 'real' and that it is an 'artefact'. Most cytologists probably realize the logical and technical difficulties involved in defining such concepts. Dr Novikoff, in a wise article, refers to the danger of study of particles 'torn by grinding devices from a cellular milieu selected during aeons of evolutionary time'. But this is almost the only reference in the book to the cell as part of a whole living system. Drs Dalton and Felix tell us that we should be satisfied that the Golgi component 'exists in freshly isolated cells and that it may be identified by its peculiar optical properties under these conditions'. The cell that they show is described as 'isolated in 4% NaCl containing 0.1% methylene blue'—no wonder the appearance was 'peculiar'.

The reader will learn more from the articles that deal with mitochondria. There are stimulating discussions of the appearance of these under different conditions, and of whether they show fundamentally different types of structure within any one cell. Discussion of the relationship between enzymic activity and the various particles appears sporadically. D. E. Green discusses the 'cyclophorase' system in relation to cellular organization. It is clear that we are not yet ready to discuss how the many isolated findings by electron-microscopists and biochemists are related to cell functioning as a whole.

Many of the articles are illustrated by good figures, but it is irritating to have to turn many pages to find the description of them. Many of them do not carry scales and one suspects that the magnifications given in round figures in the text must be incorrect.

J. Z. YOUNG

MAMMALS

The Life of Mammals, by J. Z. Young. Pp. xv + 820. Oxford University Press, London. 1957. 84s. net.

The most important point to make in any appraisal of this work is that it is not just another book on the structure and function of mammals. It is planned and written in terms of a concept, which

may in itself not be new, that animals are self-controlling systems whose activities are devoted to the maintenance of a stable pattern. But so far as I know, no major synthesis has previously been attempted to interpret the now vast accumulation of facts in the fields of anatomy, physiology, embryology, ecology, and genetics, in terms of what is now also known of the principles and properties of machines that regulate themselves. It would be a complete mistake to conclude from this that the author has decided that animals are nothing more than servomotors. On the contrary, he has used this concept as a principle to be applied as far as it will go, which means as far as scientific evidence will allow, in order to understand better how animals live. They remain alive because they make the appropriate responses during development when they build themselves, and in adult life when they maintain themselves. They make use of the data provided by heredity, by the environment, and by a store of information which they have amassed (also called experience) and which they either keep to themselves as memory or communicate to fellow-members of their species by social contacts, and in the case of man to posterity by tradition whether oral or written. Finally, the self-regulating pattern is coded into the hereditary material of the genes for the succeeding generation.

It is by failure to make appropriate responses that organisms succumb to natural selection. It is by the reshuffle of genes that have undergone mutation that selection favours those types that are regulated to make the most appropriate responses to their environments (whether changed or not), and this is evolution. The interpretation of organisms in terms of the control mechanisms by which life is maintained is therefore applicable to all fields of biology, and provides a unifying concept in a field where descriptive and comparative methods have already produced numerous generalizations, and analysis has yielded innumerable principles of partial and restricted applicability. What Professor Young has been looking for is a language which describes the whole living organization. There will be time enough to know whether there are any aspects of that organization that resist integration in this system. Meanwhile he has provided a framework, as Darwin said of his own work, 'to guide our speculations'.

Special praise must be accorded to

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the illustrations by Miss E. R. Turlington and Miss J. I. D. de Vere, and to the production of the volume by the Clarendon Press. GAVIN DE BEER

THE RETICULO-ENDOTHELIAL SYSTEM

Physiopathology of the Reticulo-Endothelial System. A Symposium organized by The Council for International Organizations of Medical Sciences, edited by B. N. Halpern, B. Benacerraf, and J. F. Delafresnaye. Pp. xii + 317. Blackwell Scientific Publications, Oxford. 1957. 45s. net.

A volume devoted to the reticulo-endothelial system will always receive a warm welcome, since there is scarcely a corner of medicine into which this important concept does not intrude.

A graceful introduction by Vallery-Radot is followed by a useful, concise account by Policard of the morphology and physiology of the reticulo-histocytic cell, as he prefers to call it, and Sadron states the principles that are used to determine the shape and dimensions of globular proteins in solution.

Three main aspects of the reticulo-endothelial system are then discussed in some detail. In the first instance, the factors that influence the functional efficiency of the system form the subject of four interesting papers based upon methods for estimating the rate at which particles of various sizes are 'cleared' from the blood and englobed by reticulo-endothelial (R.E.) cells. Everything depends, of course, on the soundness of the claim that the particles favoured by each particular investigation behave as stated. They must preserve their individuality during the period of quantitation and show no tendency to stick together in clumps, as is admitted to happen so frequently in the pulmonary vessels, and removal must be strictly by way of R.E. cells. The reviewer finds it difficult to accept these assumptions light-heartedly, although several workers state quite definitely that nearly all of the introduced material can be accounted for in the liver and spleen. Granted these assumptions, many striking features emerge, such as the remarkable selective capacity of the liver for small amounts of particles, the dependence of phagocytosis on rate of flow of blood past the phagocytes, instances of preferential phagocytosis, and the avidity of the spleen for large particles.

The second group of papers is devoted to certain aspects of R.E. cell meta-

bolism. Byers *et al.* suggest, with proper caution, that R.E. function is important in the normal disposal of chylomicron cholesterol and Vanotti gives a balanced discussion of the metabolism of iron. Miescher's account of the disposal of red blood corpuscles by the system is a model version of an exasperating, often muddled topic. Hahn and his colleagues describe their fascinating experiments on the production of cirrhosis and ascites by massive irradiation of the R.E. systems with radioactive gold colloids, and Nöller gives concisely much information on the storage capacity of the system and the way in which it can be modified by drugs.

The third aspect of the symposium brings us face to face with the most engaging question of medicine, the defence against infection. Miles summarizes his views on local defences and their relation to general R.E. defence; Halpern *et al.* apply their quantitative methods to experimental infection; Cruchaud and Tekul decide that cortisone modifies antibody distribution in an organism by increasing the proportion of cellular antibodies to circulating antibodies. Gell discusses the nature of some tissue hypersensitivity reactions and Doan discusses R.E. cells generally in relation to health and disease. We owe to Lewis Thomas a little masterpiece on the role of the reticulo-endothelial system in the reaction to endotoxins, which is a delight to read because of its clarity and provocative outlook. G. R. CAMERON

DE MOTU CORDIS

Movement of the Heart and Blood in Animals. An anatomical essay by William Harvey, translated from the original Latin by Kenneth J. Franklin. Pp. xii + 209. Published for the Royal College of Physicians of London by Blackwell Scientific Publications, Oxford. 1957. 17s. 6d. net.

William Harvey died on 3rd June 1657, in his eightieth year. A tercentenary congress of those interested in him, in his work, and in its innumerable modern developments was held in London and at his birthplace, Folkestone. This translation of Harvey's great book *Exercitatio anatomica, De motu cordis et sanguinis in animalibus* was a highly appropriate presentation to the members of the Congress.

Harvey's text was first issued in Latin at Frankfurt am Main in 1628 by William Fitzer. The publication of this book was a landmark in science, since it both laid the foundations of

modern experimental physiology and provided a firm mechanical basis for many hundreds of thousands of important clinical observations during the three following centuries.

The 1628 edition is of only some 72 pages. Both the Latin version and the English translation reproduced by Professor Franklin occupy about the same space. But Harvey himself had a quite conspicuously bad handwriting, and the 1628 text is a wretched piece of printer's workmanship, full of errata, some acknowledged by the printer himself. It has often been reproduced, both in facsimile and reprint, and has several times been translated. Professor Franklin, we think wisely, did not base his English version on the stately and scholarly edition issued by the Royal College of Physicians of London in 1766. His new English version undoubtedly excels in literary grace, and in exactness of rendering, any that has yet appeared. It will therefore automatically take its place as the standard version, for it is prepared not only with a high sense of scholarship and with accurate knowledge of its original, but also with the unique mastery that Professor Franklin possesses of the difficulties that presented themselves to Harvey and to the public that he was addressing.

All this makes us regret the more that this admirable effort is presented without any commentary and with no attempt to relate the history of Harvey's discovery. For such matters Professor Franklin is uniquely equipped. We can but hope that he will find the leisure to complete the task that he has begun in so masterly a fashion.

CHARLES SINGER

CROP PROTECTION

Plant Protection Conference 1956. Pp. xi + 315. Butterworths Scientific Publications, London. 1957. 50s. net.

Great improvements have been made during the past thirty years in the yields and quality of crops all over the world. The chemical control of pests, diseases and weeds, the breeding of plants resistant to attack, and better methods of nutrition and husbandry have all played a part. This book reports the proceedings of a Conference, attended by 200 scientists from 42 countries, convened by Plant Protection Ltd., to discuss the fundamental aspects and future trends of the new science of crop protection.

Sir Frank Engledow, in a stimulating

opening address, calls attention to the dependence of crop protection upon the basic sciences, and to the responsibilities of scientists in ensuring that its practice is built upon a sound foundation. The world aspects of the subject are ably reviewed by J. G. Knoll (Food and Agricultural Organization of the United Nations), who discusses the pests and diseases of international importance and the collaborative measures taken for their suppression. The problems arising in the breeding of plants resistant to attack are dealt with by W. F. Hanna (Ottawa), and the application of genetics in raising cotton resistant to blackarm disease is described by R. L. Knight. A valuable contribution on the physiology of immunity of plants is made by Professor Suchorukov (U.S.S.R.). The mechanisms of toxicity of fungicides and insecticides are examined by S. A. E. McCallan (U.S.A.), J. W. L. Beament, and J. T. Martin, while systemic compounds for pest, disease and weed control receive special attention from R. L. Metcalf (U.S.A.), E. Åberg (Sweden), V. J. Masten and J. Hočevár (Yugoslavia), and P. W. Brian. Assessments of hazards to operator and consumer of crop protection chemicals and of residual effects in soil are made by J. M. Barnes, R. Fabre and R. Truhaut (France), and F. J. D. Thomas (Australia). The mechanics of formation of spray droplets are discussed by R. P. Fraser and methods of spray application are described by Van den Muijzenburg (Holland) and R. C. Rainey.

Crop protection is expanding rapidly, and it is essential that, from time to time, inter-related aspects should be reviewed and placed in proper perspective. The book admirably fulfils this purpose. It contains a wealth of authoritative information, both in the formal papers and in the excellent discussions which are fully reported. Great credit is due to the organizers of the Conference in covering the subject on such a broad basis.

J. T. MARTIN

BRITISH INDUSTRIAL PROGRESS

Industry and Technical Progress, by C. F. Carter and B. R. Williams. Pp. viii + 244. Oxford University Press, London. 1957. 25s.

This report, written by two economists, contains the results of a most

painstaking analysis of the factors influencing the application of science in British industry. But in spite of all the work that has gone to its compilation, it is a disappointing document, as it fails to give the bold and imaginative lead that it admits is so badly needed in many firms. One chapter is devoted to showing why it was inevitable that certain discoveries first made in Britain should have been developed elsewhere. Take the transistor. Would it not have been more helpful if we had been told of the very effective system of administration of research and development in the Bell Telephone Laboratories that helped so much in the development of the transistor and of much besides? What of Calder Hall, Britain's outstanding technical achievement? Why are we not told of the bold and unique way in which research was there tied in with the engineering effort, making its rapid progress possible?

Little is said about the role of the engineer on whose intuition and experience the successful application of research so largely depends. Greater productivity is one of the main aspects of technical progress, and there Work Study, developed so largely under the stimulus of an engineer, Sir Ewart Smith, is the sequel to Operational Research, a war product of scientific analysis.

The rather half-hearted assessment of the advantages of the presence of scientists on the Board, with its nicely balanced arguments, may have been valid in the past, and will no doubt be comforting to those who are suspicious of engineers and scientists at the policy-making level; but will it be equally true in the future, when in many firms their products ten years hence are unknown today?

HAROLD HARTLEY

HISTORY OF TECHNOLOGY

A History of Technology, Vol. II. The Mediterranean Civilizations and the Middle Ages, edited by Charles Singer, E. J. Holmyard, A. R. Hall, and Trevor I. Williams. Pp. lviii + 802. Clarendon Press, Oxford. 1956. £8 8s. net.

Volume II of this splendid work carries on the story of the development of western technology from c. 700 B.C. to c. A.D. 1500.

It is a fascinating period of world history. It starts with the rise of the

Greek city-state from the ruins of the Mycenaean culture. The famous philosophers of ancient Greece reached heights of intellect which were not surpassed for 2000 years; but they gave little encouragement to the mechanical arts which, wrote Xenophon, 'carry a social stigma and are rightly dishonoured in our cities'. So in the end Greece was overrun by the more practical Romans, in spite of the exertions of Archimedes, who is described in this volume as 'the greatest military engineer of all antiquity'.

The Romans were an intensely practical nation. They adopted and extended the techniques of the conquered nations of the East, and spread them over the West. 'Their practical knowledge of machinery was not surpassed until the eighteenth century', writes R. J. Forbes with some pardonable exaggeration. But when the Roman Empire at last fell, like a mastodon grown too heavy for its legs to support, Western Europe relapsed into a state of lethargy and dirt. Technology was stagnant for centuries, except in a very few instances, such as the casting of bronze church bells, which were common in the ninth century. 'That peculiar creation of the mediaeval age', Froude called them.

There was a revival in the eleventh century. It was not due to any particular inventiveness in Western Europe but rather to the easier passage of new learning and techniques from the East. Even so, a citizen of Ancient Rome arriving in England at the end of the fourteenth century, after 1000 years of sleep, would have found little in the way of technology to wonder at, and much to condemn.

The period ends with the appearance on the scene of that astonishing genius Leonardo da Vinci at the time when what Carlyle, in the middle of the nineteenth century, called 'the three great elements of modern civilization—Gunpowder, Printing and the Protestant Religion' had begun to exert their influence.

One reads of the details of these changes with absorbing interest in the volume before us. It is beautifully illustrated and produced. And one closes it, temporarily, with a feeling of gratitude to the editors and authors, and to the great Company which has made the work possible.

H. T. TIZARD

Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

The Uniqueness of the Individual, by P. B. Medawar. Pp. 191. Methuen & Co. Ltd., London. 1957. 18s. net.

This book is a collection of ten essays on major problems of biology written by Professor P. B. Medawar during the decade 1946-56. It takes its title from the last of these essays, which was written specially for the book. They deal in the main with problems of evolution. The earlier essays have been somewhat revised and annotated to take note of new ideas and to correct errors.

The Analysis of Engineering Structures (third edition), by A. J. S. Pippard and J. F. Baker. Pp. xii + 564. Edward Arnold (Publishers) Ltd., London. 1957. 60s. net.

The purpose of this well-established book is to offer students of engineering a general outline of the theories on which the design of structure is based. A substantial part of the book has been rewritten since the last edition (1943), and some material now readily available elsewhere has been omitted. Arches, rings, and bow-girders are now differently treated, by the more elegant method of super-position. An important revision is that of the chapter on retaining walls, which has been rewritten by Dr A. W. Bishop.

Colorimetric Analysis (second edition), Vol. I, by Noel L. Allport and J. W. Keyser. Pp. xi + 424. Chapman and Hall Ltd., London. 1957. 50s. net.

This is a completely new version of N. L. Allport's 'Colorimetric Analysis', originally published as a single volume in 1945. Since that time the methods and applications of colorimetric analysis have so greatly extended as to make it necessary to publish the new edition in two volumes under joint authorship. This first volume deals with the use of colorimetry in biochemical and clinical analysis: the second volume will deal with metals, foods, pharmaceutical products, and so on. As in the original edition, there is no theoretical discussion. The methods described are critically assessed and their limitations are emphasized.

Physics of Fully Ionized Gases, by Lyman Spitzer. Pp. ix + 105. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London. 1956. Paper covers \$1.75; bound, \$3.50 net.

Although completely ionized gases are encountered only in exceptional circumstances, those containing an almost negligible proportion of neutral atoms are of considerable practical as well as theoretical interest. For example, in the Sun and the solar corona helium exists mostly as nuclei stripped of the two orbital electrons. This account of the theory of gases consisting wholly of nuclei and electrons is intended for students who have some knowledge of theoretical physics but have made no special study of the kinetic theory of gases.

Ciba Foundation Colloquia on Ageing. Vol. III, Methodology of the Study of Ageing, edited by G. E. W. Wolstenholme and Cecilia M. O'Connor. Pp. x + 202. J. and A. Churchill Ltd., London. 1957. 32s. 6d. net.

This discussion, the third within the field of gerontology to be organized by the Ciba Foundation, was prompted by the fact that a number of long-term experiments are in hand to study the changes with age that occur in man and certain animals. In such experiments proper methodology is of the first importance. This volume contains thirteen papers on gerontological methods presented at the colloquium, together with the discussion that followed.

American Institute of Physics Handbook, edited by Dwight E. Gray. Pp. xi + 1523. McGraw-Hill Book Co. Inc., New York; McGraw-Hill Publishing Co. Ltd., London. 1957. £5 12s. 6d. net.

This is a highly concentrated collection, by ninety specialists, of up-to-date and well-documented physical tables, graphs, and formulae. There are eight sections: on mathematics, mechanics, heat, sound, electricity and magnetism, optics, atomic and molecular physics, and nuclear physics. The last two sections occupy about one-third of the book. The subjects are liberally interpreted: data will be found, for example, relating to such

diverse fields as geodesy, oceanography, radio-astronomy, and aerodynamics.

The Encyclopedia of Chemistry, edited by G. L. Clark and G. G. Hawley. Pp. xvi + 1037. Reinhold Publishing Corporation, New York; Chapman and Hall Ltd., London. 1957. 156s. net.

This is a collection of articles on pure and applied chemistry. It is written by some five hundred different American experts, and the emphasis is upon American practice. Cross references and an index give some assistance in finding information on topics not given a specific heading.

The First One Hundred and Fifty Years. Pp. xxv + 242. John Wiley & Sons Inc., New York. 1957.

The story of John Wiley & Sons, the scientific publishers, has been written to mark the 150th anniversary of the firm's foundation. It is of interest not merely because of its account of the evolution of a small general publisher into a leading firm in the highly specialized business of scientific publishing, but because it incidentally throws interesting sidelights upon certain aspects of American history since 1807. Handsomely produced, this book is a fitting commemoration of a century and a half of notable achievement.

Statistical Methods in Research and Production, with Special Reference to the Chemical Industry (third edition), edited by Owen L. Davies. Pp. x + 396. Published for Imperial Chemical Industries Ltd. by Oliver and Boyd, Edinburgh. 1957. 45s. net.

This standard handbook of statistical methods for scientific and industrial research workers has been substantially revised since the last (1954) edition. Seven of the eleven chapters have been completely rewritten. Subjects introduced for the first time include the economics of testing and experimentation; sequential sampling; the analysis of covariance; and the estimation of variance components and confidence limits. In the new treatment reliance is placed more on confidence limits than on tests of significance.

R. E. RICHARDS,
M.A., D.Phil.,

Was born in 1922 and educated at Colyton Grammar School, Devon, and St John's College, Oxford. From 1944 until 1947 he worked on infra-red spectroscopy in the Physical Chemistry Laboratory at Oxford and in 1948 was elected Senior Demy, Magdalen College. Shortly afterwards he succeeded N. V. Sidgwick as Fellow of Lincoln College. He has since worked on the physical properties of clathrate compounds, and during the past eight years has been exploring the chemical applications of nuclear magnetic resonance, upon which he has published numerous papers. He was awarded the Corday-Morgan Medal of The Chemical Society for 1954, and held a Research Fellowship at Harvard University in 1955.

R. N. ROBERTSON,
B.Sc., Ph.D., F.A.A.,

Was born in Melbourne in 1913 and was educated at St Andrew's College, New Zealand, and the University of Sydney, where he became Linnæan Macleay Research Fellow in plant physiology. In 1936 he came to Cambridge for three years to continue his studies with an 1851 studentship. He returned to Sydney in 1939 as assistant lecturer in botany, later becoming lecturer. In 1946 he joined the Commonwealth Scientific and Industrial Research Organisation, and is now chief research officer in the Division of Food Preservation and Transport. His research has been mainly concerned with the movement and accumulation of salts in plants; mitochondria; and the physiology of fruit development and ripening.

CYRIL STANLEY SMITH,
D.Sc.,

Was born in Birmingham in 1903. He was educated at Bishop Vesey's Grammar School, the University of Birmingham, and, after emigrating to the United States in 1924, the Massachusetts Institute of Technology. He spent fifteen years as research metallurgist with the American Brass Company, and during the war he directed the work in metallurgy at the Los Alamos Laboratory. In 1946 he was appointed the first director of the Institute for the Study of Metals of the University of Chicago, a post which he has recently resigned in order to devote more time to laboratory work. He remains professor of metallurgy in the Institute. He has been awarded the U.S. Medal for Merit, and medals of the Franklin Institute and the American Institute of Mechanical Engineers. His research has been in the fields of the constitution and structure of alloys, the metallurgy of plutonium, and the role of surface energy in determining the shape of microconstituents in alloys. On leave from the University in 1955-56, he lived in London and devoted himself to research on the history of science and technology, in which he had long been interested.

E. F. WARBURG,
M.A., Ph.D.,

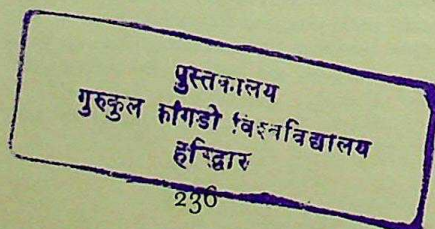
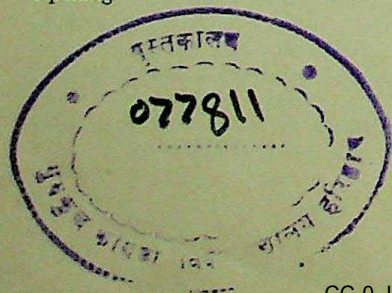
Was born in 1908 and was educated at Marlborough College and Trinity College, Cambridge. Formerly a Fellow of Trinity College, Cambridge, he is now Curator of the Druce Herbarium, Oxford University. He has worked mainly on the taxonomy of British plants and is joint author of the 'Flora of the British Isles'. He is editor of *Watsonia*, the Journal of the Botanical Society of the British Isles.

H. GUTFREUND,
Ph.D.,

Was born in Vienna in 1921, and came to England in 1938. Between 1943 and 1956 he was associated with several Cambridge University research units first as a research student, then as Assistant in Research in Colloid Science, and lately as Imperial Chemical Industries Research Fellow. He worked first on the structure and properties of protein molecules in solution and during the last four years on the chemical mechanisms of enzyme reactions. In 1952 he was a Rockefeller Foundation Fellow in J. S. Fruton's laboratory at Yale University and since then has spent several periods as Research Associate at the Sterling Chemistry Laboratory of Yale University. He has recently been appointed to the staff of the National Institute for Research in Dairying, where he will continue his study of enzyme mechanisms.

G. PORTER,
M.A., Ph.D., F.R.I.C.,

Was born in 1920 and was educated at the Universities of Leeds and Cambridge. Following war service as a radar officer, he carried out research in the University of Cambridge, where he developed techniques for the observation and study of unstable chemical species. He was elected a Fellow of Emmanuel College, later becoming a demonstrator, then an assistant director of research in physical chemistry. In 1954 he became assistant director of the British Rayon Research Association and in 1955 he was appointed to the chair of physical chemistry in the University of Sheffield. This year he received the Corday-Morgan Medal of The Chemical Society.



Some books received

(Note. Mention of a book on this page does not preclude subsequent review.)

BIOLOGY

Biological Aspects of the Transmission of Disease, edited by C. Horton-Smith. Pp. viii + 184. Published for the Institute of Biology by Oliver and Boyd, Edinburgh. 1957. 21s. net.

Cold Spring Harbor Symposia on Quantitative Biology. Vol. XXI, Genetic Mechanisms: Structure and Function. Pp. xviii + 392. The Biological Laboratory, Cold Spring Harbor, New York. 1956. \$8 net.

BOTANY

Progress in the Study of the British Flora. Report of the Conference held in 1956 by The Botanical Society of the British Isles, edited by J. E. Lousley. Pp. 127. The Botanical Society of the British Isles, British Museum, London. 1957. 20s. net.

CHEMISTRY

Chemical Process Economics in Practice, by J. James Hur. Pp. iv + 115. Reinhold Publishing Corporation, New York; Chapman and Hall Ltd., London. 1957. 32s. net.

Chimica Analitica degli Alimenti, Vol. II, by Giulio Buogo. Pp. 497. Casa Editrice Ceschina, Milan. 1956. Lire 4500 net.

La chimie nucléaire et ses applications, by M. Haissinsky. Pp. vi + 651. Masson et Cie, Paris. 1957. Paper covers, Fcs. 5000; bound, Fcs. 5600 net.

Chimie organique générale, by Jean Vène. Pp. 349. Masson et Cie, Paris. 1957. Paper covers, Fcs. 3500; bound, Fcs. 4100 net.

Elementary Practical Organic Chemistry. Pt. I, Small Scale Preparations, by Arthur I. Vogel. Pp. xv + 347 + xiv. Longmans, Green & Co., London. 1957. 21s. net.

Encyclopedia of Chemical Reactions, Vol. VI, compiled by C. A. Jacobson and edited by Clifford A. Hampel. Pp. 438. Reinhold Publishing Corporation, New York; Chapman and Hall Ltd., London. 1956. 100s. net.

Instrumental Analysis, by Paul Delahay. Pp. xi + 384. The Macmillan Company, New York and London. 1957. 55s. 6d. net.

Microchemical Journal, Vol. I, No. I, edited by Nicholas D. Cheronis and others.

Pp. 166. Published under the auspices of The Metropolitan Microchemical Society by Interscience Publishers Inc., New York. 1957. Annual subscription \$9.60 net.

Organic Synthesis, Vol. I, Open-Chain Saturated Compounds; Vol. II, Open-Chain Unsaturated Compounds, Alicyclic Compounds, Aromatic Compounds, by Vartkes Migrdichian. Pp. xxviii + 833 and pp. xiii + 835-1822. Reinhold Publishing Corporation, New York; Chapman and Hall Ltd., London. 1957. £14 the set.

Précis des matières colorantes synthétiques. Vol. II, Matières colorantes, by Henri Wahl. Pp. 398. Presses Universitaires de France, Paris. 1957. Fcs. 2800 net.

ENGINEERING

Engineering Uses of Rubber, edited by A. T. McPherson and Alexander Klemin. Pp. 490. Reinhold Publishing Corporation, New York; Chapman and Hall Ltd., London. 1957. 100s. net.

Quality Control for Plastics Engineers, edited by Lawrence M. Debing. Pp. iii + 142. Reinhold Publishing Corporation, New York; Chapman and Hall Ltd., London. 1957. 40s. net.

GENERAL SCIENCE

On Human Communication, by Colin Cherry. Pp. xiv + 333. The Technology Press of Massachusetts Institute of Technology, and John Wiley & Sons Inc., New York; Chapman and Hall Ltd., London. 1957. 54s. net.

Realities of Space Travel, edited by L. J. Carter. Pp. 431. Putnam & Co. Ltd., London. 1957. 35s. net.

Route-Mapping and Position-Locating in Unexplored Regions, by W. Filchner, E. Przybyllok, and T. Hagen. Pp. 288. Birkhäuser Publishing Co., Basle. 1957. Sw. Fcs. 32 net.

GEOLOGY

L'évolution de la lithosphère. Vol. II. Orogenèse, by Henri Termier and Geneviève Termier. Pt. I, pp. 498; Pt. II, pp. 503-940. Masson et Cie, Paris. 1957. Each part: paper covers, Fcs. 9000; bound, Fcs. 9800 net.

MATHEMATICS

The Fascination of Numbers, by W. J.

Reichmann. Pp. 176. Methuen & Co. Ltd., London. 1957. 15s. net.

Mathematics and Statistics for use in Pharmacy, Biology and Chemistry, by L. Saunders and R. Fleming. Pp. x + 257. The Pharmaceutical Press, London. 1957. 27s. 6d. net.

MEDICINE

British Pharmaceutical Codex 1954, Supplement 1957. Pp. xiii + 124. The Pharmaceutical Press, London. 1957. 27s. 6d. net.

Manual of Radiation Therapy, by K. Wilhelm Stenstrom. Pp. xxx + 94. Charles C. Thomas, Publisher, Springfield, Illinois; Blackwell Scientific Publications, Oxford. 1957. 34s. net.

The Visual Pigments, by H. J. A. Dartnall. Pp. vii + 216. Methuen & Co. Ltd., London; John Wiley & Sons Inc., New York. 1957. 30s. net.

METALLURGY

Chromium, Vol. II, Metallurgy of Chromium and its Alloys, by Marvin J. Udy. Pp. viii + 402. Reinhold Publishing Corporation, New York; Chapman and Hall Ltd., London. 1956. 88s. net.

PHYSICS

The Calculation of Atomic Structures, by Douglas R. Hartree. Pp. xiii + 181. John Wiley and Sons Inc., New York; Chapman and Hall Ltd., London. 1957. 40s. net.

The Defect Solid State, by T. J. Gray, D. P. Detwiler, D. E. Rose, W. G. Lawrence, R. R. West, and T. J. Jennings. Pp. vii + 511. Interscience Publishers Inc., New York; Interscience Publishers Ltd., London. 1957. \$11 net.

The Hypercircle in Mathematical Physics, by J. L. Synge. Pp. xii + 424. Cambridge University Press, London. 1957. 70s. net.

Vorlesungen über Atomphysik, Vol. I, by J. Picht. Pp. viii + 238. Deutscher Verlag der Wissenschaften, Berlin. 1956. DM 18.60 net.

TECHNOLOGY

Die technischen Anwendungen der Radioaktivität, by Engelbert Broda and Thomas Schönfeld. Pp. x + 313. Verlag Technik, Berlin. 1956. DM. 19.

सन्दर्भ ग्रन्थ
REFERENCE BOOK

यह पुस्तक वितरित न क ज्ञाय
NOT TO BE ISSUED







